The Application of Data Farming and Wargaming to Coalition Decision-Making

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ABSTRACT

Data Farming is a methodology that combines simulation modeling, rapid scenario generation, high performance computing, experimental design, analysis and visualization, and collaborative processes. Data farming is a quantified approach that examines questions in large possibility spaces and evaluates whole landscapes of outcomes to draw insights from outcome distributions and outliers. Wargaming is an activity not involving actual forces, but represents military operations in conflict situations of various types. Wargaming normally attempts to adjudicate sequential player decisions within a representation of simultaneity. Each player, who can represent a nation-state or other political-military entity, takes actions in turn based on the current situation and within the limits of the game as to their ability to react to the most recent moves made by players before them during a game turn.

In this paper we describe our work combining the power of data farming with wargaming in order to demonstrate the synergies between the two in capturing the dynamic interaction among friendly, adversary, and other forces. We discuss our work with a Hybrid Warfare scenario involving coalition forces requiring extensive knowledge of the decision-makers and their long-term goals, their risk attitude, their rational and irrational constraints, diplomatic capabilities, and strategic agility. In particular, we consider the elements of conventional forces and irregular forces; police forces and influence on urban/rural areas; force mix of political, military, industrial, and cyber warfare initiatives; national threat influence from beyond borders, election interference and external propaganda effects; and impacts of cyber and national infrastructure interference.

ABOUT THE AUTHORS

Gary Horne is the Technical Director of M&S Solutions at MCR Global with a doctorate in Operations Research from The George Washington University. During his career in defense analysis, he has led data farming efforts examining questions in areas such as humanitarian assistance, convoy protection, and anti-terrorist response. He chaired the NATO Modeling and Simulation Task Group MSG-088, *Data Farming Support to NATO*, which completed documentation of the data farming process and won a NATO Scientific Achievement Award. His continued work with NATO includes service as co-chair of the task group *Data Farming Services* and in this task group he is focusing on cyber questions. He has led the Data Farming Community through the 32 International Workshops that have taken place to date and is planning the 33rd Workshop scheduled to take place in Finland in October 2018.

Wayne Stilwell is the CEO of Stilwell Technology and Robotics, LLC, with a doctorate in systems and information engineering from the University of Virginia. During his career as a US Army officer with a specialty in simulations operations, he held several leadership positions in wargaming and data fusion/system interoperability development and operations. He has led data farming workshop teams in Finland and the US. He holds a patent pending in robotic interfaces, which focuses on data exchange between cooperative robots. His company is actively engaged in developing drone-swarming techniques across land, sea and air operations. He currently teaches manufacturing technology, commercial drone applications, FAA unmanned systems examination preparation, and cyber technology at community colleges as well as online for high schools.

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INTRODUCTION

Data Farming is a quantified approach that examines questions in large possibility spaces using modeling and simulation. It evaluates whole landscapes of outcomes to draw insights from outcome distributions and outliers. This evaluation is made possible by "growing" massive amounts of data through the execution of many simulation runs. The name *Data Farming* was initially coined in 1997 (Horne 1997). Since that time the data farming community has grown to include people from over a dozen nations. Data farming continues to evolve from initial work in a United States Marine Corps effort called Project Albert (Hoffman and Horne 1998) to work including that done at data farming workshops which number 32 to date. The *Scythe* is the publication of the International Data Farming Community that contains proceedings of these workshops (i.e. Meyer and Horne 2014, etc.) and that can be found at www.datafarming.org.

Data farming normally uses simulation in a collaborative and iterative team environment (Horne and Meyer 2004) that has been used primarily in defense applications (Horne and Meyer 2010). This process ideally has input and participation by subject matter experts, modelers, analysts, and decision-makers. Data farming is a process that has been developed to support decision-makers by answering questions that are not currently addressed. Data farming uses an inter-disciplinary approach that includes modeling and simulation, high performance computing, and statistical analysis to examine questions of interest with large number of alternatives. Data farming allows for the examination of uncertain events with numerous possible outcomes and provides the capability of executing enough experiments so that both overall and unexpected results may be captured and examined for insights.

In 2010, the NATO Research and Technology Organization started the Modeling and Simulation Task Group *Data Farming in Support of NATO* to assess and document the data farming methodology to be used for decision support. This group was called MSG-088 and this paper includes a summary of the six realms of data farming as outlined during the course of MSG-088 (Horne et al. 2014). Upon completion of MSG-088, a follow-on task group called *Developing Actionable Data Farming Decision Support* was initiated by NATO and was designated MSG-124. This task group has completed work in selected application areas important to NATO and was focused on iterative exploration of "what-if?" questions to reveal the landscape of possibilities inherent in the scenarios and enable the study of any outliers that were discovered. A new NATO task group, designated MSG-155 has since been formed and has begun to develop the topic of *Data Farming Services*.

In this paper we describe our work combining the power of data farming with wargaming in order to demonstrate the synergies between the two in capturing the dynamic interaction among friendly, adversary, and other forces. We discuss our work with a Hybrid Warfare scenario involving coalition forces requiring extensive knowledge of the decision-makers and their long-term goals, their risk attitude, their rational and irrational constraints, diplomatic capabilities, and strategic agility. In particular, we consider the elements of conventional forces and irregular forces; police forces and influence on urban/rural areas; force mix of political, military, industrial, and cyber warfare initiatives; national threat influence from beyond borders, election interference and external propaganda effects; and impacts of cyber and national infrastructure interference.

DATA FARMING

Data farming uses an iterative approach that is illustrated by the loop of loops in Figure 1 (www.datafarming.org). The first realm, rapid prototyping, works with the second realm, model development, iteratively in an experiment definition loop. A rapidly prototyped model provides a starting point in examining the initial questions and the model development regimen supports the model implementation, defining the resolution, scope, and data requirements. The third realm, design of experiments, enables the execution of a broad input factor space while keeping the computational requirements within feasible limits. High performance computing, realm four, allows for the execution of the many simulation runs that is both a necessity and a major advantage of data farming. The fifth realm, analysis and visualization, involves techniques and tools for examining the large output of data resulting from the data farming experiment. The final realm, collaborative processes, underlies the entire data farming process and these processes will be described in detail in this section. These realms are described in detail in Horne et al. 2014, but will be summarized below.

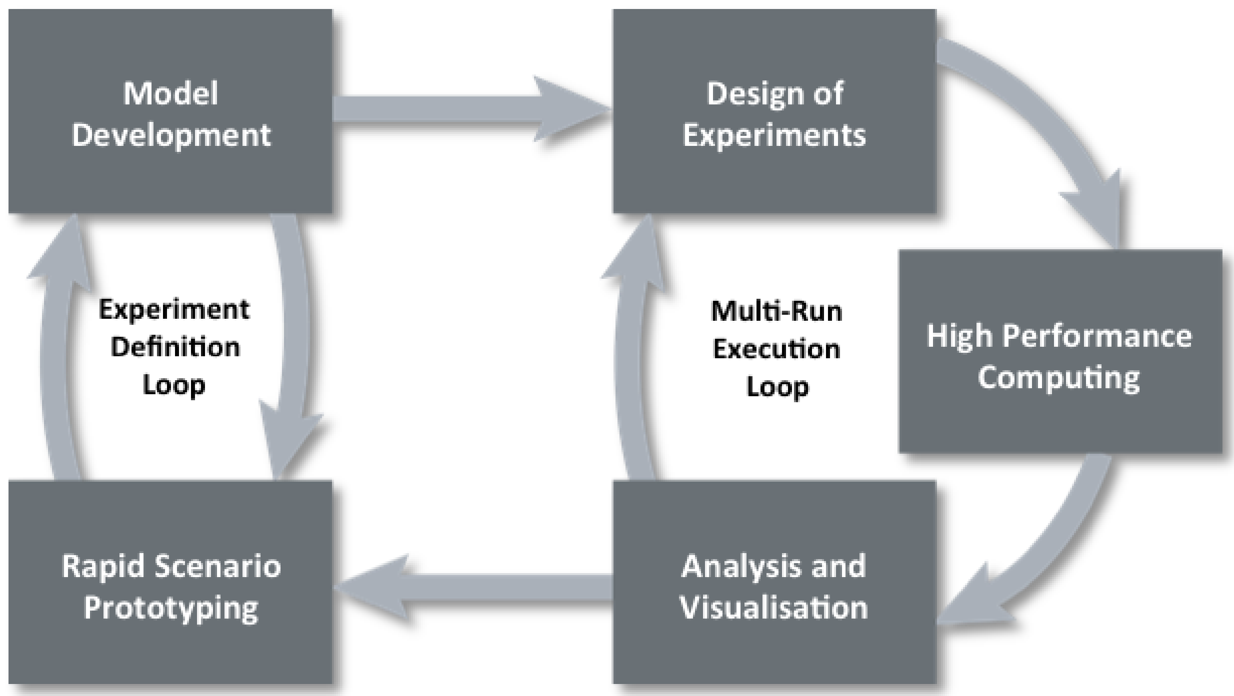

Figure 1: Data Farming Loop of Loops

Rapid Scenario Prototyping

The model development and the rapid prototyping realms of data farming together make up the experiment definition loop in Figure 1. As such, they work hand-in-hand with each other and we could choose either realm to begin our detailed description of data farming. Thus the rapid scenario prototyping process is a good place to start our discussion, although starting with the model development realm would also be appropriate.

As with the data farming process in general, the rapid scenario prototyping should always be within the context of the questions to be answered. These questions have to be prepared in such a way that simulation can help to find answers and to get insights. The most important step here is to define measurements to be collected by means of simulation together with required input and output data for the simulation. In most cases this step already requires some rough ideas about the scenario settings. Thus, this realm simply represents the initial formation of the basics of a scenario to be simulated.

Model Development

As stated in the previous subsection, the model development realm works hand-in-hand with the rapid scenario prototyping realm in the experiment definition loop on the left side of Figure 1. The fundamental output of this loop is a scenario instantiated in a working simulation model that captures the essence of a question and that can be sent to the multi-run execution loop of the data farming process. Of course, more insight into the question, refinement of the question, and/or deeper examination of the question may be enabled later through a return to the experiment definition loop later in the process.

When developing models, both modeling and subject matter experts should be present. Rapid scenario prototyping provides model requirements for model development. For example, it is important to do one thing well, such as creating aggregated models that combine simple models instead of building single monolithic models, whenever possible. The more independent models are from each other, the better the potential results. Thus, one needs to encourage modularization and clear separation of different models, including development practices for using models of different aggregation level and scope. Other important characteristics of models as they are developed include reusability, interoperability, repeatability, and thorough documentation. And, finally, openness should be encouraged, including the sharing of source code when possible given other constraints.

Design of Experiments

Design of experiments is one of the three realms of data farming in the multi-run execution loop. Along with the realms of high performance computing and analysis and visualization, the realm of design of experiments allow us to perform multiple runs to gain simulation results over a wide landscape of possibilities. Simulation models have many inputs or parameters (factors) that can be changed to explore alternatives. A designed experiment is a carefully chosen set of combinations of these inputs, called design points, at which the simulation model will be run. Design of experiments provides smarter ways of setting up the experiment that facilitate follow-on analysis and visualization of results in a reasonable amount of time.

Changing the factors in a brute force way, by looking at all possible combinations, is impractical or impossible, except for extremely simplistic simulations with only a handful of factors. Changing the factors all at once limits your insights. It will allow you to see whether or not this changes the responses, but you will not be able to tell why the changes occur. For example, if mission effectiveness improves when you equip a squad with better sensors and better weapons, you will not know whether it is the weapon or the sensor that has the most impact. Changing the factors one at a time also limits your insights. If the squad gets a very small improvement from a better weapon, a very small improvement from a better sensor, but a large improvement from both, you will not be able to identify this interaction (or synergistic effect) if the experimental design does not involve factors for both the weapon and the sensor.

High Performance Computing (HPC)

HPC consists of both hardware and software resources. HPC systems can be configured as a single supercomputer with thousands of processors, as a network of clustered computers, or even as a single powerful desktop computer with multi-core processors. The hardware on these systems includes such things as processors, memory, networking hardware, and disk storage. HPC software includes, among other things: the operating system; underlying or supporting software which provide the environment to execute the model; and the data farming software, which enables running instances of the model across the HPC system compute units. By generating and managing each of the model runs over a set of design points or input sets, the data farming software provides the infrastructure “glue” that “sticks together” the model, its set of inputs, the design, and the HPC resources.

The main purpose of HPC in the context of data farming is to provide the means to execute a data farming experiment. Other purposes of HPC are for use in analysis and visualization of the output and for generating designs used in future data farming experiments. Given the large number of model runs made in a typical data farming experiment, HPC facilitates conducting the experiment in a timely manner as well as supporting the storage and analysis of huge volumes of output.

Analysis and Visualization

Analysis in the data farming context is the process of examining data that is produced by data farming processes using statistical, summarization and presentation techniques to highlight useful information, extract conclusions, and support decision-making. Visualisation is a collection of graphical and visual analysis techniques used to optimize and speed the process of exploring data, conveying understanding, and presenting in data farming processes. Much of the current usage of analysis and visualization in the data farming process has been the analytic examination of multiple replicate and excursion model output.

In order to exploit the potentially huge data output from the high performance computing execution of the design of experiments, highly effective analysis techniques must be employed. Statistical analysis and visualisation can be used to discern whether data may have useful meaningful value and aid in the translation of data into information that is useful in making progress in understanding possible answers to the questions at hand. The ability to use multiple techniques provides the ability to explore, investigate, and answer the questions posed. Every technique has strengths and limitations, therefore, especially for high-dimensional datasets, use of a family of techniques is preferable to use of a single technique. As stated earlier, data farming gives us the ability to map the landscape of possibilities and in the process discover outliers. These outliers should always be considered and only be eliminated for appropriate reasons and can be investigated as a separate cohort of the data using various analysis and visualisation techniques.

Collaboration

The spirit of collaboration is the key tenet of data farming. It underlies the loop of loops in Figure 1 and holds within it much of the power of data farming. Throughout the development of data farming and the formation of the data farming community, people have openly shared experiences and expertise. One focus for collaborative efforts has been and continues to be the international workshops. The first international workshop took place in 1999 at the Maui High Performance Computing Center. The first four workshops were methodology driven, dealing with complex adaptive systems modeling and agent based representation, with statistical experiment design and experiment evaluation. The subsequent workshops were and continue to be application driven, and the contributions to the overall advancement of data farming takes place in the development of simulation models, scenarios within the models, and computer clusters to run the models many times.

The real work is in making progress on important questions and the real secret is the combination of military subject matter experts and highly knowledgeable and multi-disciplinary scientists. This special mix of personnel has been the hallmark of the international workshops and this mix has promoted much networking opportunity. It has been a dynamic combination to have data farming work teams headed up by a person who really knows and cares about the question (e.g. a military officer who knows that the answers may have an impact on both mission success and lowering casualties) and supported by men and women with technical prowess who can leverage the tools available.

MSG-088 documented the following aspects of the collaborative processes in data farming: defining the characteristics and dimensions of collaboration in data farming, collaboration within and between the realms in data farming, collaboration of the people, collaboration of the data farming results, application of collaboration tools. This information can be found in the full report as well as information on the current status of data farming in the attending nations and ideas about the future development of data farming (Horne et al. 2014).

Some Recent NATO Data Farming Work

In 2017, the Operation Planning Team and Cyber Team of MSG-124 completed work on applying data farming techniques to explore solutions to improve NATO capability (Horne and Seichter et al. forthcoming). In the cyber case, the scenarios considered spanned the threat spectrum, ranging from lone hackers to cyber espionage organizations. The team utilized a NetLogo model developed by the team and the analyses focused on exploring the value of various network topologies and organizations, firewall policies and intrusion detection systems.

The US-led cyber team leveraged current research, developed a suitable simulation, and explored possible scenarios through data farming that could facilitate the understanding of aspects of cyber defense important to NATO. The group defined questions within the cyber defense area in conjunction with cyber defense experts of NATO and the participating nations, provided modeling and simulation support for various cyber defense questions, and performed analysis and iterative exploration of what-if? questions to reveal the landscape of possibilities inherent in the scenarios and enable the study of any outliers that are discovered. Complete documentation of both the cyber team work and the operation planning team work will be found in the forthcoming final report of MSG-124.

A new NATO Task Group, MSG-155, began in August 2017 with the goal of extending data farming capability and accessibility through developing Data Farming Services (DFS). The specific objective is to develop a road map for what needs to be done in order for NATO to provide DFS. This road map would show the way for developing a technical concept for DFS through an integrated toolset. Additionally, the work would produce and refine technical prototypes useful for implementation of the road map. DFS would support the application and execution of the Data Farming process as codified in MSG-088 and as applied in MSG-124 in a productive and user-friendly way.

WARGAMING AND EXPLORATION OF QUESTIONS USING DATA FARMING

Wargaming is an activity not involving actual forces, but represents military operations in conflict situations of various types. Wargaming normally attempts to adjudicate sequential player decisions within a representation of simultaneity. Each player, who can represent a nation-state or other political-military entity, takes actions in turn based on the current situation and within the limits of the game as to their ability to react to the most recent moves made by players before them during a game turn (US Army War College, 2017 and US Naval War College, 2008).

Wargaming is an extremely good candidate for data farming support due to the inherent ability to consider data within supporting simulations. Even without simulation support, wargaming preparations can anticipate decisions and prepare branches and subsequent consequences through more brute force methods of data farming. Having a ready made data harvest already developed in a wargame supporting simulation produces the opportunity to broaden the impact of data farming on wargaming.

The ability to explore large problem spaces with multiple parameter combinations and decision branches invites data farming's exhaustive search strengths to offer insights and better inform decision-making. Simulation support to wargaming becomes far more powerful when data farming is applied and can produce better-considered decisions. Wargaming, as developed in the US military over the years, has become a detailed development process that normally plays in consecutive turns. Simulation allows for greater simultaneous decisions by adversarial sides or a complex grouping of opposing allies with neutrals playing as well. Simulations have become much more capable of assigning rewards, punishments, and consequences for game decisions made by a strategic, operational or a tactical player. Typical wargames consider decisions that progress in discrete turns. In a two-sided wargame, side 1 selects from a menu of decisions, and side 2 then selects from a menu of decisions given the actions of side 1. Consequences of decisions are calculated, and the game either terminates or advances to the next round of turns. All competitive interactions can be modeled as a wargame.

Grand Bazaar Example

Take, for example, a sale at the Grand Bazaar in Istanbul in the 1700s. A Venetian trader sees some gold chains that he fancies, and he shows his interest by looking at the goods in a way that signals he is a prospective buyer. The salesman, an old hand at the game of haggling, greets him and gives him a very high price as an opening move. The traveler, wise also in the game, knows the price is too high and shows disinterest, and even looks down toward another gold sales area nearby to threaten a move to the competition. One of the parties must now initiate a second round of bargaining, or the game ends with no transaction. That series of events, in wargaming and though quite simple in concept, introduces a host of possibilities and branches. The price the salesman offers originally can be thought of as a decision based on a large possibility space. He might have a general price that is always the opening price, and is designed to greatly overcharge the poorly informed buyer. The profit potential of even a few sales may be worth the likely balking of some buyers who, based on the very high price, move on to another salesman immediately. The opening price might also be based on a combination of input parameters such as time of day, the dress of the customer, the apparent strength of interest by the customer, the volume of sales over the past few hours, and the general mood of the salesman. A multi-variate space of exploration is quickly created. From the salesman's perspective, data farming could be used to look for lucrative combinations of parameters that increase profit. After simulating many runs of different customer types, their patience and haggling skills, their balking likelihood, correlations of dress and interest to final price agreement, the salesman can much more successfully engage customers in the haggling game's opening round.

Data farming could set the table for the second round by providing likely price openings from the customer, or the likelihoods of a customer pause that is inviting a second, lower price from the salesman. With many branches of possibilities already developed in simulation via data farming, the second round can open with a final no from the customer, an agreement on price, or a counter-offer that will mark the beginning of the next round of negotiations.

Natural Disaster Example

A deeper example of multiple sided data farming can be illustrated through the desire of national intra-governmental agencies to better develop response policies. The wargame, in this case, focuses on a developing country that has had a major natural disaster and is in a more remote continental location. Multiple agency heads can congregate to react to initial news of the disaster, while executive leadership decides how much aid and support a nation will contribute to the effort. The efforts quickly begin to consider many factors of importance to the operation: How time sensitive is aid by what type, what other countries and agencies will vie for port, airhead, or rail delivery facilities, how long will it take to develop and deliver a logistics supply line, what security risks are involved, and how many ships, planes, soldiers, aid workers, supplies, and other assets should be committed.

Decisions of the wargame participants begin to take shape as questions such as: should they participate?, how much should they participate?, how long should they plan on supporting such an operation?, and what order should aid and infrastructure be engaged?

Outcomes are developed as the amount of relief successfully delivered, lives saved, costs sustained, assets obligated, redundancy between countries and agencies, and others as applicable. Third order and long term effects of how aid and security operations affect power in the affected region, long-term stabilization, and governmental changes because of intervention can be studied as well.

Data farming in such a wargaming exercise would grow data in each round of decisions and their effects on subsequent rounds. Data can be regrown based on decision points through the rounds and take on a Bayesian paradigm in that once a set of decisions are made in a given round, the question then becomes, what happens afterwards? Decisions made by a single player affect future decisions, but they also serve to often magnify or diminish the benefits or damage done by other players simultaneously in a round. If all players in the disaster relief scenario decide to engage what are typically limited port facilities simultaneously, then many ships sit in a harbor waiting to be unloaded. Starvation could be exacerbated and tragic considering food is sitting on ships and delivery is delayed due to competition for handling equipment. This chain of events could alter the next round of decisions by a player to do something about the current situation by engaging more aircraft than initially committed and/or reshuffling its order of deliveries in hope of ameliorating a bottleneck situation. It could be that the airhead becomes clogged, and other ports with overland transportation links could be considered. That could require more ground transportation assets, road repair and upgrade, and additional parameter inclusions in the data farming model.

As more branches are identified or developed, a simulation that can incorporate data farming becomes a powerful tool for better decision-making. The consequences and risks of decisions are better illustrated. Actual decisions at the national level should be extremely well explored, well understood events and based on the best information available given time and expense of collection. Data farming can drastically reduce the time and expense of decision support information while greatly expanding the breadth of consideration.

Cuban Missile Crisis Example

An example of a government taking unknown risks was discovered during the post-mortem of the Cuban Missile Crisis. During discussions of the fateful events of 1962 years later, diplomats of the Soviet Union revealed that nuclear attack authority had been released to the field commander (Sechser and Fuhrmann, 2017), meaning that a general and not the head of state could now use nuclear weapons as he saw fit for operational and tactical advantage without oversight and constraint by the strategic implications of his actions. The chance of a nuclear attack by the Soviet Union on the forces of the United States was far more likely than American diplomats and military planners realized. The Americans were actually firing depth charges on a Soviet nuclear submarine and the possibilities for nuclear strike were much greater than realized. Only the restrained thinking of a local Soviet military leader kept the confrontation from being nuclear. As the Americans fully considered amphibious invasion, the Soviet response was already sealed as a nuclear counter-strike, unbeknownst to the American leaders.

FUTURE WORK

Data farming does not necessarily help leaders make the exactly correct choice in a wargame or allow for the consideration of all parameters that should be examined in an important decision. It can, however, greatly increase the clarity of decisions based on a complex set of known parameters and a larger decision interaction space than the human mind can well consider. The sheer volume of possibilities to consider becomes enormous to the point of requiring high speed computing. The ability to think through a previous actual event is obviously easier to draw conclusions from given that likely outcomes of decisions can be verified. The wargaming of future events requires a much more detailed and exhaustive ability to scour the depths of decision ramifications and the branches of co-adaptive environment decisions that result.

Integrating Data Farming and Wargaming

Simulation tools, as they exist, can be adapted to include data farming in support of wargaming. JTLS, JCATS, JDLM, VBS3, and other tactical and strategic simulations can provide data into a data farming software application that sets the original table for the wargaming of a strategic or tactical option within a greater scenario. JTLS provides outstanding support of theater level logistics and can provide command and control system input data. A data farming application can be developed in support of such simulation tools that can return multiple scenario input data to set the table for multiple possible scenarios. A simulation can then develop multiple instantiations of start points for wargaming turns that can be auto run for analytical purposes, or that can be available as branches of wargame decisions through simulation support. Interoperable simulation federations with data exchanging between many simulations and command and control systems can also be greatly assisted through strap-on data farming module support.

AI can also be harnessed to develop likely parameter growth in decision branches and automatically grow data. Experimental design within hardened parameters can be auto-generated and rapidly, through high performance computing, continuously develop wargame decision branches and their subsequent likely consequences and third order effects. The auto-generation of a data farming cycle could bring a much more powerful and responsive edge to complex environments and systems decisions.

Hybrid Warfare

One specific topic area of potential future work is Hybrid Warfare. Hybrid Warfare is an extremely complex game of cat and mouse that uses all of the influence, force, threat, power and nuance that a nation-state can muster. As the technological march of time has progressed, nation-states wield far more communicative power over lethal forces and can retract major forces from engagements shortly before they occur. The addition of cyber attack capabilities to undermine or embarrass a government adds another significant variable to an environment that also includes diplomacy, alliances, peacemaking, economic influences, and any form of use of power that advances a nation-state towards a particular goal. Data farming quickly becomes a strongly desired capability when the combinations of use of force and other types of national power are so nuanced and rapidly interchangeable.

The ability to describe many sides, alliances, uses of force and their relative effectiveness to other players, costs and consequences of actions or inaction, and the second and third order effects create branches of possibility that are enormous in scope. Examining Hybrid Warfare scenarios involving coalition forces requires extensive knowledge of the decision-makers and their long-term goals, risk attitude, rational and irrational constraints, diplomatic capabilities, and strategic agility. High performance computing and the experimentation strengths of data farming become not only desired but also necessary under these conditions. In future work we must consider such factors as the elements of conventional forces and irregular forces; police forces and influence on urban/rural areas; force mix of political, military, industrial, and cyber warfare initiatives; national threat influence from beyond borders, election interference and external propaganda effects; and impacts of cyber and national infrastructure interference.

As a further example of possible future work in the area of Hybrid Warfare, suppose an aggressor nation has a goal of pacifying a small neighbor's governmental will to the point of becoming a satellite. The aggressor gives continual threats to scare its people into submission, issues passports to the small country's citizens, conducts cyber attacks to weaken public trust in banks, transportation, emergency services, and public governance, and masses troops on the small border regularly as intimidation. The responses of the smaller country have many possibilities, but usually fall in the range of public defiance and ally seeking while doing all it can to dissuade the larger country from attacking through diplomacy. The integration of data farming into a wargaming process to help the smaller country's decision making would require reliable data from military, economic, public infrastructure, and industrial sources. There would necessarily be a red force player who was either a team of experts on the likely behaviors and reactions of the larger country, or an artificially intelligent agent that would make decisions according to a validated model. Once reliable data is introduced into such a wargame by a useful simulation capability, then data farming can be harnessed to examine the range of possibilities and likelihoods in support of decisions. The discovery power of data farming can possibly find new perspectives, new concerns, and possible strategies that may not be evident to the naked eye. Based on the risk of miscalculation multiplied by the severity of nuclear warfare, advancing data farming support of wargaming would be well worth the effort required.

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