THE PEACE OF WAR - A POLITICAL GAME THEORY ANALYSIS OF THE ONGOING RUSSIA AND UKRAINIAN WAR

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ABSTRACT

The mighty scourge of war is a natural evil, yet through that evil there may be a peace worthy of saving nations for generations to come. Despite war's differences there is a universality in its similarities, meaning that with analysis and application it would be possible to predict specific outcomes of war. Political game theory in the form of extensive form games, and the metagame theory analysis algorithm can be used to help find these outcomes. Essentially by using mathematical models it would be possible to predict the most likely outcome of a specific conflict.

At the time that this is being written, there has been 11 months of ongoing war between Ukraine and Russia regarding the Ukrainian territory and whether Russia has a natural right to that previously dominated land. To test the peace algorithms generated and explained in this work, we will apply them to this ongoing Russia - Ukraine crisis in an attempt to predict the most likely outcome of the war. From there a strategy can be formed to determine the most peaceful means to achieve those ends. Should the algorithms be correct, then the prediction would match whatever might be the physical resolution to the conflict. War can be an awe-inspiring display of evil and yet through war's darkness there might be a lurking peace that can be found with the proper application of political game theory and mathematics. Hence this work, the Peace of War.

ACKNOWLEDGEMENTS

Honors are reserved for those who excel beyond what is typically found, and with UC Riverside already being an institution of excellence, it becomes difficult to imagine that there are those who still excel beyond the norm. Still, the University Honors program at UC Riverside manages to be composed of both students and faculty who do exactly that: excel. Throughout my time as a student in the program I was seldomly left unassisted, but instead was often guided by the helpful hands of the honors team. The curriculum and resources of the honors program similarly helped to prepare me for a future in graduate education where I may be able to continue to produce good natures.

A key player in that system of excellence has been my faculty mentor, Professor Indridi H. Indridason. As a professor of political science specializing in applied game theory, Professor Indridason has been a pivotal player in this specific capstone project, and in my overall passion for political science. Him, along with the University Honors faculty and staff, have been true conduits of change within my educational career and within the university. Although the title of honors is usually reserved for the students within the University Honors program, its meaning should also be applied to each of the faculty, staff, and respective faculty mentors for their continued excellence that is beyond the already standard level of excellence within UC Riverside.

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INTRODUCTION

Conflict is almost universal and is oftentimes inevitable, as has been demonstrated throughout history. Aristotle brought about this same assertion in writing that “the art of war will also be in some sense a natural form of the acquisitive art” (Aristotle, 2008). Yet as long as there has been war, there has also been efforts to stop it, and these efforts persist today in the ways of conflict resolution and political game theory. This concept known as political game theory essentially models how individuals make decisions, and what decisions an individual might make next. Two such forms of game theory are extensive form games, and the metagame analysis algorithm (henceforth referenced as MA) of Fraser and Hipel which are both inherently different forms of game theory, but still within the umbrella nonetheless. Using various forms of game theory such as these allows for studying real world disputes to both learn from them and potentially prevent similar disputes in the future.

Recently, game theory has become an effective tool for analyzing conflicts in the academic world and in the public sector alike, but there are certainly some barriers of entry for many political scientists. Game theory was initially developed within the area of economics where various mathematical techniques are more reinforced, making game theory the analysis of choice for mathematical maniacs and not necessarily for political personas. A heavy reliance on data analysis and diagram implementations has also heightened the entry barriers for political science. Extensive form games fall into the area of diagram implementation and the metagame analysis algorithm finds its way into some of the more complex mathematical techniques, making it a little less common in the area of political game theory until just recently. Certainly, there have been texts focusing on the use of either extensive forms games or the metagame analysis algorithm, and many of these are referenced in this particular capstone, but it seems that there has perhaps never been a culmination of both approaches in order to analyze a particular conflict. This apparent gap in the field in what this capstone seeks to fill.

RUSSIA & UKRAINE - BACKGROUND

The major purposes of this capstone is the application of various types of political game theory in order to reinforce each unique approach, demonstrate the applicability of game theory, and also predict potential outcomes to current conflict. The conflict at hand is the ongoing war between Russia and Ukraine that began February 24th, 2022. At the time that this is being written, it has been slightly over a year since the invasion and yet a year later, Ukraine still stands. Putin's decision to wage war against Ukraine was based on his belief that Russia had an original right to Ukrainian territory because it once possessed the land as part of the USSR. This logic is what led to his full scale invasion of Ukraine's sovereign territory which has killed tens of thousands of people and harmed millions more (U.S. Department of State).

Despite the main invasion taking place in 2022, this war's roots date back to 2013 when Russia wrongly labeled the seditionists conflict in Crimea as a civil war. Ukraine first became an independent state in 1991, and although there were some lapses in peacetime, violence was a long ways away. It wasn't until November of 2013 when President Viktor Yanukovych decided not to sign the EU-Ukraine Association Agreement that caused a shift (Arel, 2022). This decision introduced a power shift in favor of western Russian values and ultimately resulted in the Euromaidan / Maidan uprising. Seeing opportunity, Putin strategically sent his military to annex Crimea and Ukraine in areas that would meet little resistance. The unofficial war had already taken many lives when Vladimir Putin made the war truly official by launching a full scale military invasion to try and break Ukraine in early 2022. Interested readers may wish to develop a more complete picture of the ongoing crisis and should do so using the references list following this work. The particular reference, “Ukraine’s Unnamed War - Before the Russian Invasion of 2022” , is of particular importance and can help those interested in furthering this political game. Still, for this specific political game, the previous background should suffice.

OBJECTIVES & CONSIDERATIONS

At this point in time (April 2023), just over a year has passed since Russia's initial invasion of Ukraine with no end in sight. Although it will be discussed further within the capstone, it would suffice to say that two obvious outcomes of the war could be Ukraine joining NATO and negotiating peace, or Russia successfully annexing Ukraine. In order to predict which of those outcomes might occur, a simplified version of the game will be employed using both extensive form games and the metagame analysis algorithm. The application of these concepts will be used to both reinforce their use in the field of political science, and also to predict possible outcomes for the conflict in question.

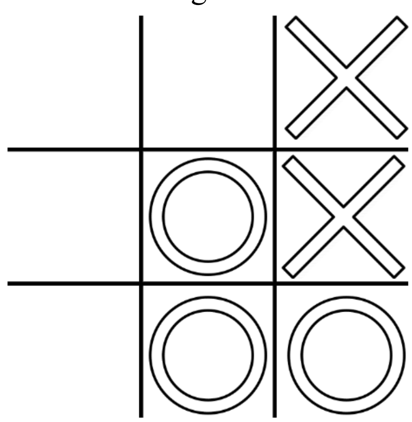
While this work serves to further the application of game theory within political science, it also plays an important role regarding the ongoing war that wouldn’t be possible if the conflict was resolved prior to this capstone’s publication. Although such a situation would affect the impact of the project, the value of saved lives from ending the war certainly outweighs any value that this project might have. Still, should the war end before the publication of this research, the project wouldn’t be entirely meaningless. Instead, extensive form games and the metagame analysis will still be used to develop outcomes and those outcomes will serve as a way to reinforce the importance of the concepts, should the outcomes match the true resolution of the conflict. This would then simply become a stronger case of applied research.

All of these considerations are mentioned because of their possibilities to impact the project, but none should be extensive enough as to truly alter the work. Unpredictability is a common factor in war as it is in research, such that both need to be adaptive to the situation at hand. Still, there are meanings in both and perhaps through a culmination of research and war, specifically how research can apply to war, there can be a resulting peace to last for decades to come.

METHODS OF CONFLICT ANALYSIS

When considering game theory, it is often helpful to start by thinking about strategy at an entry level, and one way to do so is to think back at the tic-tac-toe games a child might find on a kids menu at the local diner. Deciding where to scribble an "x" or an "o" requires some strategic thinking (although it might be a very skewed version of strategic thinking), and the action is done with the intention to win the game. To demonstrate this concept of rational choice, examine Figure 1 below and scribble in the next, most strategic move, as the "x" player.

Figure 1:



When deciding where to place the "x" it is likely that any player would consider the moves that prevent the other player from winning. Each move is calculated in some way to maximize a player's chances at winning or avoiding a cat's game[1], and although the next move

[1] Cat's game / a tie game in tic-tac-toe comes from the notion that a cat will run in circles trying to impossibly catch its own tail just like a player in tic-tac-toe who can't win a game that is tied.

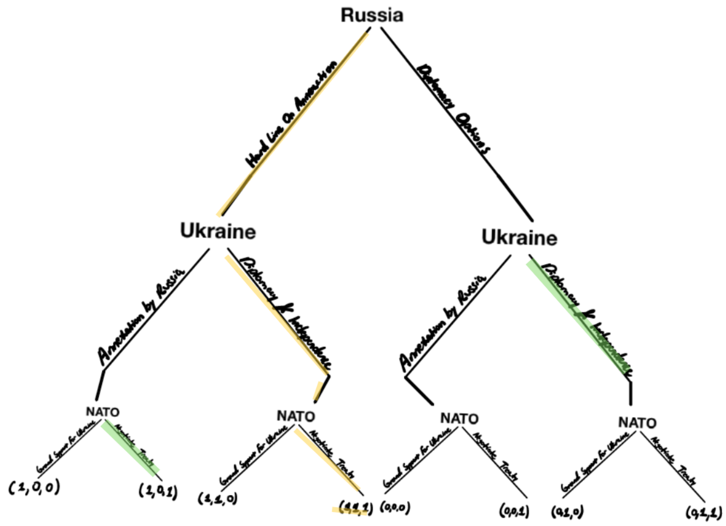
for player “x” would never result in a victory, there are certainly a couple of strategies that would be the most rational. It is the purpose of game theory to explain how and why an individual would make a decision like placing a specific “x”. Furthermore, game theory operates on rational choice theory, which is the notion that individuals should rationally pursue goals subject to constraints imposed by physical resources as well as the behavior of other actors. A simple game of tic-tac-toe helps to demonstrate these high level game theory concepts with an entry level game.

For more complex games that aren’t drawn on dinner menus with faded crayons, it is important to be familiar with the proper terminology. The participants in a conflict model are called players who make and decide actions/options that impact other players. A grouping of these options is referred to as a strategy, and the results from these respective strategies are known as outcomes of the games. Both the extensive form game and metagame analysis below use these terms diligently.

EXTENSIVE FORM GAME ANALYSIS

It was mentioned that there would be two game theory approaches utilized in this capstone, with one of them being the extensive form game analysis. This approach refers to a form of game theory that models sequential and non-simultaneous actions. In light of the Russia and Ukraine war, this would mean analyzing actions in a specific order where Russia might act first and then Ukraine must act in response to that move. Of course this also means that there can be variations of the game depending on the orders in which the players act. An example of the extensive form game that will be looked at later can be seen below in Figure 2.

Figure 2:



The game in Figure 2 includes 4 components, as does most extensive form games. These components are the actors/players, the sequences of actions/terminal histories, the player functions (who acts when), and the outcomes of the game. The extensive form game analysis and its 4 respective components make up the initial analysis of the conflict in question and can be seen in the subsequent section: Study Area & Data.

METAGAME ANALYSIS

The second mode of analysis is accomplished through the metagame analysis algorithm of Keith W. Hipel and Niall M. Fraser. This form of game theory, referred to as “the mathematics of relations” (Fraser, 1988) constitutes an approach for realistically modeling the social and psychological properties inherent in conflict situations, but it does so in a simultaneous fashion. This approach has been successfully employed in a number of other conflicts, but it seems that it hasn’t been paired with an extensive form of game analysis. A couple of the many pieces to the metagame analysis algorithm can be found in Figure 3.

Figure 3:

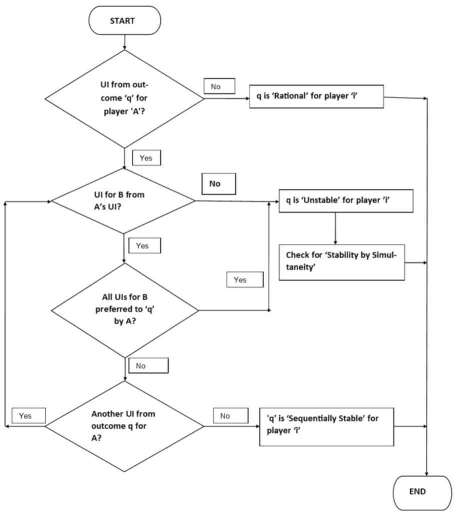


Table 5: Stability Analysis

Russia	**X**	**E**	**X**	**X**	**X**	**X**	**X**	**X**	**Overall Stability**
	r	s	r	u	u	r	u	r	**Individual Stability**
	1	5	3	7	0	4	2	6	**Preference Vector**
		4		6	1		3		**UI**
Ukraine									
	r	r	u	s	r	r	u	u	**Individual Stability**
	6	2	4	0	7	3	5	1	**Preference Vector**
			6	2			7	3	**UI**
NATO	r	s	r	s	u	u	u	r	**Individual Stability**
	6	4	7	5	2	0	3	1	**Preference Vector**
		0		1	6	4	7		**UI**

The above metagame analysis algorithm (also referred to as MA) is a useful form of game theory analysis because it can handle larger and complex games. Due to the rigorous mathematical foundations of MA, prior uses of the metagame analysis algorithm used a computer algorithm for efficiency (Fraser, 2004). Still, the smaller scope of this game didn't require such technology. Instead the analysis was done by hand.

UNCERTAINTIES

Combining both extensive form games and the metagame analysis should allow for a deeper multi-factor approach to game theory that hasn't been done, all the while reinforcing both theories and increasing the validity of the results. This combination also allows for a sharpened approach when looking at political uncertainty. Political uncertainty refers to questions that can arise in a game such as what are the available courses of action to each player? What are the player's ordinal preferences and feasible outcomes? What are the possible compromise solutions? How sensitive is the game to slight changes in preferences by other players? What happens if a player forms a coalition? How can the dynamic aspects of the game evolve over time? Utilizing both approaches should allow for answers to each of these uncertainties.

Trained political scientists, economists, or game theorists in general may notice that both the extensive form game, and the metagame analysis are condensed when compared to other expanded versions of political games. The same readers would also understand that it's often opportune to first study condensed models for a conflict and then use the insights gained to expand into more complex games in the future. Likewise, considering the expansive nature of the ongoing Russian and Ukrainian conflict in question, it was decided to condense the more complex interactions of the game and instead focus on the application and combination of the extensive form game with MA. As such, all readers are welcomed to use the included game analysis as a platform for any expanded studies in the area; afterwards feel free to use the backs of the pages as a blank canvas to practice tic-tac-toe strategy for the next restaurant diner menu game bout.

STUDY AREA AND DATA

Two different games require two different breakdowns, and for visualization purposes it was decided to start the study with the extensive form game. Recall that the current background of the war at hand demonstrated the sheer complex nature of the interaction. Therefore any game that attempts to accurately model the conflict could entail numerous players and hundreds of potential outcomes, and while the mathematical nature of the metagame analysis algorithm is more conducive to such an approach, extensive form games are not. This is another reason for the condensed approach taken in this analysis. With that in mind, potential outcomes were determined for the conflict and recorded in Table 1.

Table 1: Players, Options & Outcomes

Player	Option	Strategy	Outcome
Russia	Hard line on annexation	Preferred Strategy	**1**
	Diplomacy		**0**
Ukraine	Annexation by Russia		**0**
	Diplomacy & independence	Preferred Strategy	**1**
NATO	Ground support for Ukraine		**0**
	Negotiate Treaty	Preferred Strategy	**1**

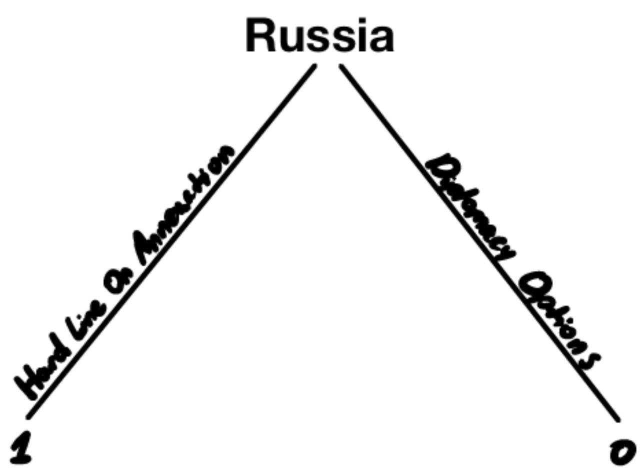
The above table shows each of the players involved in the conflict being analyzed. While Russia and Ukraine are certainly the main players of the game, there is an argument to be made that other nations like the United States or neighboring countries like Belarus should be players as well. For this reason, NATO was included in the game as a one size fits all solution to the many other nations that could be added to the game, making it much too long for an initial analysis. In a continuation of the condensed project nature, each player was limited to only two options which are essentially variations of choosing between peace actions or war. These options were assigned payouts denoted by a column of binary 1's and 0's indicating the value that each player sees in that respective outcome. To make it more clear, the text "preferred strategy" was included next to each player's most liked option which is also shown by a higher payout of 1 instead of 0.

These same outcomes will be continued in the metagame analysis, and in both cases might be written horizontally ie. (1,0,1) to express a set of preferred strategies by each nation. In this outcome (1,0,1), Russia is taking a hard line on the annexation of Ukraine, while Ukraine allows itself to be annexed and NATO attempts to negotiate a peace treaty. Many other strategies derive from this table, and so it is important to reference it throughout the analysis.

For more complex games, it is also important to gather accurate information in order to predict all the possible outcomes whether they are feasible or not. This is often done through dialogue with an expert in the field or through obtaining written material. Either way it is important to contact knowledgeable experts, and the references in this capstone are a testament to that.

EXTENSIVE FORM GAME

Figure 4:



To start the extensive form game, the players, options, and outcomes noted in Table 1 are transitioned into a diagram that will grow throughout the course of the game. The information in Table 1 corresponding to Russia, can now be seen in Figure 4 with each option and outcome portrayed. This visual diagram shows that should Russia choose to walk down the path of annexation they would be fulfilling their preferred outcome and receive a payout of 1, as opposed to seeking diplomacy where the payout would be 0.

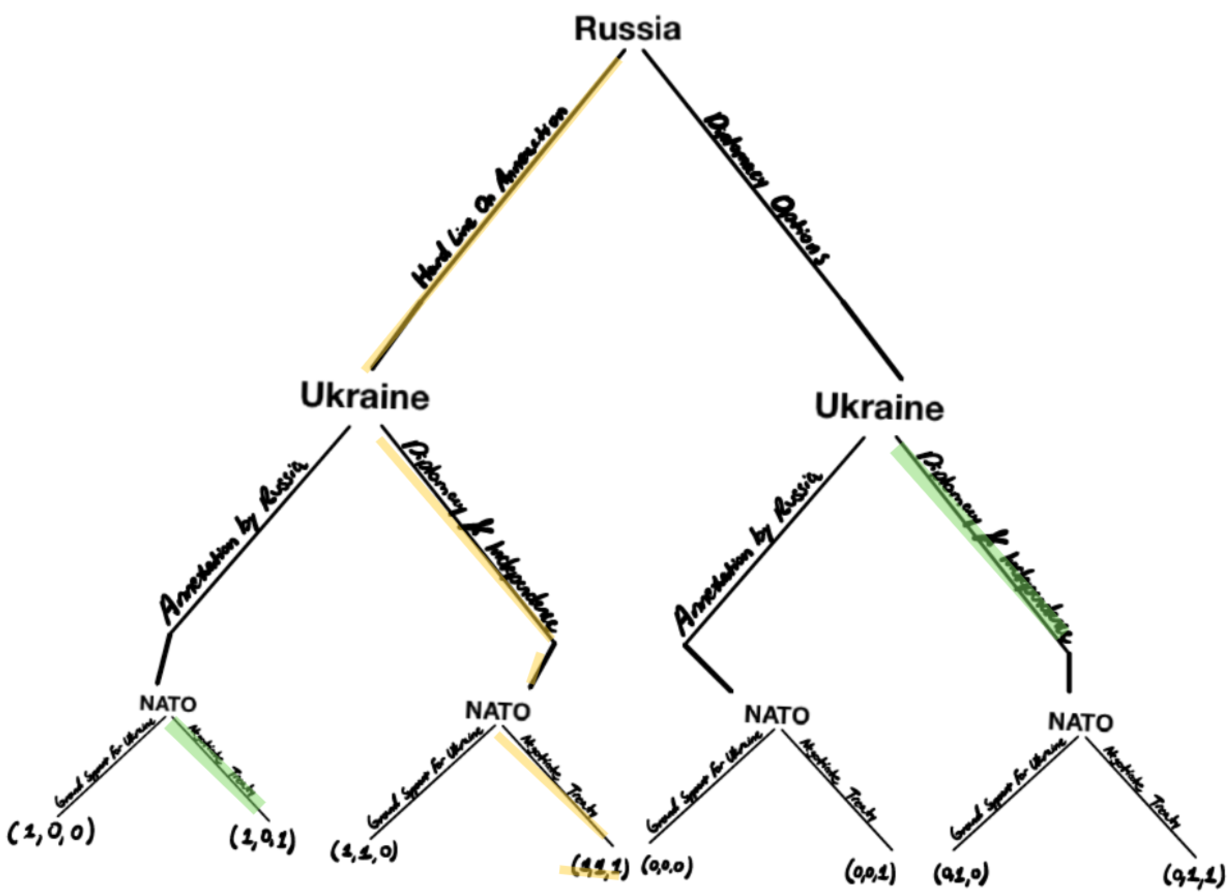
Figure 5:

The same options, and outcomes written in Table 1, are again continued in Figure 5 which shows Ukraine and its respective options and outcomes. The same is done with NATO and is displayed below in Figure 6.

Figure 6:

As was mentioned in the methods section, extensive form games allow for sequential and non-simultaneous actions where players respond to the actions of the prior player. Due to this, the game can be seen in multiple parts that culminate to form the full extensive form game. Each part is essentially a subset of the full game that represents the actions available to each specific player. Stacking these parts allows for the full game where players act in response to each other's choices. This full game can be seen in the figure below.

Figure 7:



With the extensive form game drafted above, it came time to utilize backward induction in order to solve the game itself. This concept of backwards induction means starting at the bottom of the game and working up to select each player's most preferred strategy in response to another player's strategy. Doing so showed that in each sub game, NATO would choose to negotiate peace rather than send ground support for Ukraine and risk furthering the conflict. As a result, the game shows that Ukraine would always act by pursuing diplomacy and independence to which Russia would respond with a hard line on annexation. This ordering results in the path of play of (HA,DI,NT) which equates to the outcome of (1,1,1).

Pundits of the game would notice that the subgame perfect equilibrium of the game is (HA, DI, DI, NT, NT, NT, NT), but this is hardly necessary to note for this specific analysis. Furthermore, it should be mentioned that this game also overlooks the uncertainty that could take place with how likely each player is to actually follow through with their strategy. This is in continuation of the forethought to try and keep the initial analysis condensed at an undergraduate level. Nonetheless, this potential uncertainty will be mentioned later on in the results section.

For now it is more important to note that the predicted path of play is (HA,DI,NT) which equates to the outcome of (1,1,1) . This corresponds to a predicted outcome where Russia would seek to annex Ukraine, who would then choose to offer diplomacy and strive for independence all the while NATO tries to negotiate a treaty.

METAGAME ANALYSIS ALGORITHM

Undergoing the metagame analysis of the conflict still uses the same players, options, and outcomes originally noted in Table 1, but does so in a much more math intensive way. This second approach allows for a simultaneous analysis (as opposed to the sequential analysis done with the extensive form game), and is much more conducive to large scale conflict analysis'. Still recall that due to the rigorous mathematical foundations of MA, prior uses of the metagame analysis algorithm used a computer algorithm for efficiency (Fraser, 2004). Nevertheless, the smaller scope of this game didn't require such technology. Instead the analysis was done by hand.

Notice that Table 1 demonstrates that there are a total of 6 options in the game for both the extensive form game and in this metagame analysis. This means that there are 2^6 = 64 mathematically possible outcomes. Of these outcomes there are many that may be impossible for a variety of reasons, and such outcomes are labeled as "infeasible outcomes" In even more complex games, there may be up to thousands of infeasible outcomes, but for this specific case there isn't nearly as much. Some, but not all of these infeasible outcomes are noted in Table 2.

Table 2: Infeasible Outcomes

Player	Option	Outcome
Ukraine	Counter invasion of Russia	✗
NATO	Allow Ukraine to join NATO	✗

Table 2 shows two examples of infeasible outcomes known to this game. The first is a counter invasion of Russia by Ukraine which is infeasible because Ukraine simply lacks the military capability to attempt a counter invasion at this time. The second infeasible outcome is for the National Atlantic Treaty Organization to allow Ukraine to join NATO. Such an occurrence is an impossibility as well, because NATO requires certain military, economic, and GDP criteria of its members, and Ukraine cannot meet those requirements as of this moment. These outcomes, and many of the other infeasible outcomes have been removed from the game because of their impossibility. When these infeasible outcomes are removed, there are 8 remaining feasible outcomes that are depicted in Table 3. These feasible outcomes are the same feasible outcomes that were available in the previous extensive form game.

Table 3: Feasible Decimalized Outcomes

Outcome	Calculation	Decimalized Outcome
(1,0,0)	1x2^0 + 0x2^1 + 0x2^2 =	1
(1,0,1)	1x2^0 + 0x2^1 + 1x2^2 =	5
(1,1,0)	1x2^0 + 1x2^1 + 0x2^2 =	3
(1,1,1)	1x2^0 + 1x2^1 + 1x2^2 =	7
(0,0,0)	0x2^0 + 0x2^1 + 0x2^2 =	0
(0,0,1)	0x2^0 + 0x2^1 + 1x2^2 =	4
(0,1,0)	0x2^0 + 1x2^1 + 0x2^2 =	2
(0,1,1)	0x2^0 + 1x2^1 + 1x2^2 =	6

Besides displaying the feasible outcomes for the analysis, the above table serves a greater purpose of explaining the shorthand for each outcome. Previously the outcomes have been written in the binary form of (1,1,0), but in order to make the next steps of the analysis more efficient, the outcomes have been decimalized in order to turn three numbers into one number. For example, the outcome (1,1,0) is now represented by the decimalized number 3. This simple arithmetic operation doesn't change the value of any of the outcomes, but simply serves to clean up the work for later operations in the game.

With the new decimalized versions of the outcomes, it becomes easier to demonstrate the preferences of each player. In most cases, players will prefer certain outcomes like how it is likely for Russia to prefer outcome 1 instead of outcome 0 because Russia receives a higher payout from the former. When the feasible outcomes for a player are listed from left to right, this ordering becomes the preference vector for that player. These preferences vectors are shown in Table 4. To help with the ordering of these preferences, lexicographic ordering is used[2].

Table 4: Preference Vectors

	Most Preferred							**Least Preferred**
Russia	1	5	3	7	0	4	2	6
Ukraine	6	2	4	0	7	3	5	1
NATO	6	4	7	5	2	0	3	1

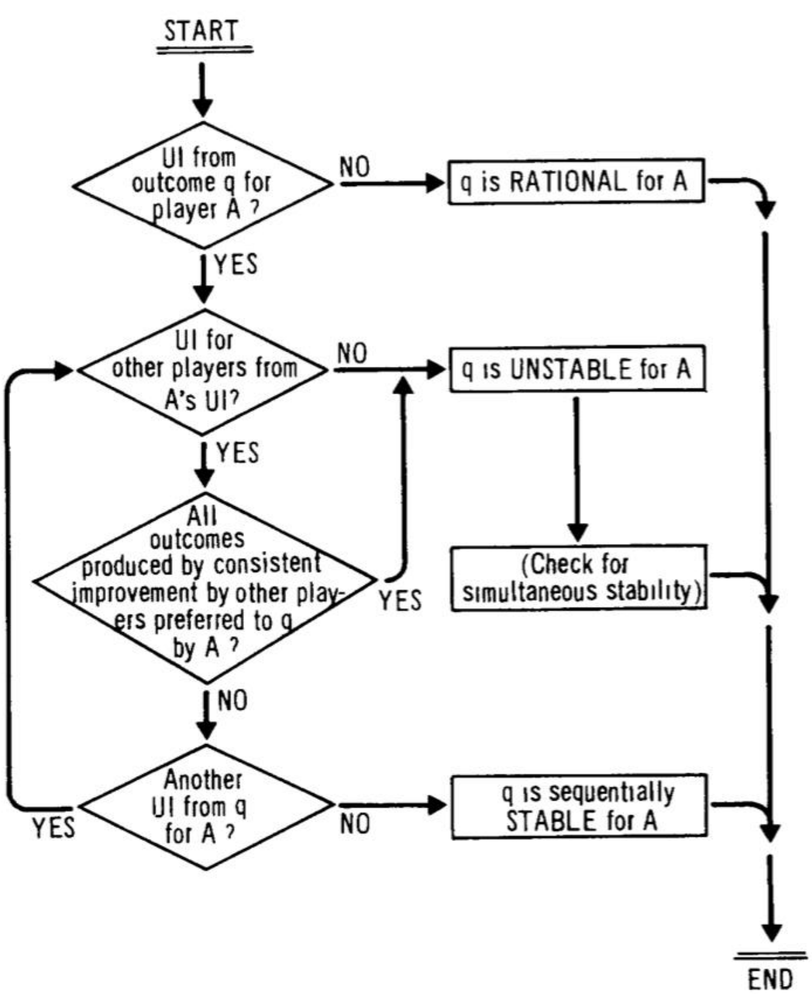
This specific part of the metagame analysis algorithm is where the validity of the algorithm gets questionable. While Fraser and Hipel are detailed in their explanation, there is still no set mathematical formula through which to determine what outcomes a player will prefer. While there are computer algorithms available to help with the lexicographic ordering of some larger games, there is still no algorithm or set of rules available for clearly organizing preferences. In some ways this same problem is apparent in extensive form games as well. Hence why it becomes important to work with knowledgeable people and sources in the field.

[2] Lexicographic ordering is the same pattern used in a dictionary where words are organized by their first letter and then second letter and so on.

This is the only way to get into the potential mindset of each player in order to determine their preferences for each outcome.

Due to the condensed nature of this game, the resulting preference vectors should be fairly accurate. For example it is fair to assume that Russia would prefer outcome 1 to outcome 5 because in outcome 1 Russia faces no opposition whereas in outcome 5, Russia faces opposition by NATO. The same logic can be applied in saying that Ukraine would prefer outcome 4 to outcome 0 because outcome 4 allows Ukraine to seek peace and independence without pushback and outcome 0 involves Ukraine not seeking peace and independence entirely. In larger games, there can often be equally preferred outcomes amongst a player, but thanks to the smaller scale of this game, we were spared that particular occurrence. No equally preferred outcomes and instransitivities were present.

Figure 8:



The main purpose of the metagame analysis algorithm is to predict possible solutions to the dispute, and the stability analysis stage of the algorithm is where most of that work is done. Analyzing the stability of each outcome allows for an insight on which outcome a player is least likely to deviate from. This stage of the algorithm is often the most complex part, which is why Figure 8 is provided to allow for a visual representation of the process. The figure shows that in order to begin the stability analysis, one must look for any unilateral improvements (UI's) where a player would change their strategy to reach a more preferred outcome while the strategies of the other players remain the same (Fraser, 2004). In some situations, there is no UI and hence that outcome is automatically stable or otherwise known as rational. Eventually, the outcome that is stable for all of the players is what becomes the solution for the MA.

Unilateral improvements are important for the simultaneous factor of this game because it emulates a player's decision to choose strategies in real time. Still, just like a player would never choose a strategy that results in an action from another player that is potentially worse, a player would also never choose a unilateral improvement that results in a less preferred outcome. This concept is mapped out in Figure 8 by showing that the only way for a stable outcome to happen is through a unilateral improvement for one player that does not result in consistent improvement by the other players.

Notice also that a section in Figure 8 is designated to "check for simultaneous stability". This stage in the analysis may be done if an outcome is unstable for two or more players, but requires the following formula:

$$p = a - (x - 1)q \quad x = 2, \ldots, m$$

This calculation is useful for more complex games and is also a calculation that is done when the computerized algorithm is available. Not to mention that Fraser and Hipel put this stage in parenthesis for a reason. Considering that this is a condensed version of the game, and the computerized algorithm is not available, the calculations for simultaneous stability were omitted. The following complete stability analysis for the game can be seen in Table 5.

Table 5: Stability Analysis

Russia	**X**	**E**	**X**	**X**	**X**	**X**	**X**	**X**	**Overall Stability**
	r	s	r	u	u	r	u	r	**Individual Stability**
	1	5	3	7	0	4	2	6	**Preference Vector**
		4		6	1		3		**UI**
Ukraine									
	r	r	u	s	r	r	u	u	**Individual Stability**
	6	2	4	0	7	3	5	1	**Preference Vector**
			6	2			7	3	**UI**
NATO	r	s	r	s	u	u	u	r	**Individual Stability**
	6	4	7	5	2	0	3	1	**Preference Vector**
		0		1	6	4	7		**UI**

Explaining the stability analysis stage of the metagame analysis algorithm can be a bit confusing and so to better demonstrate the concept, consider the green highlighted outcome.

Here, Russia has a UI from outcome 5 to outcome 4 since in both situations Ukraine would allow for annexation and NATO would explore peace options. Considering that, then Russia would prefer outcome 4 to outcome 5 because in outcome 4 Russia wouldn't have to spend money or risk troops. Despite this UI for Russia, the outcome becomes stable since the UI could result in consistent improvement by the other players. In order to avoid this Russia would remain with their original payout in outcome 5 instead of shifting to outcome 4. This outcome is stable as denoted by an “s” located in the individual stability row of table 5 where an “s” refers to a stable outcome, an “r” refers to a rational outcome, and a “u” refers to an unstable outcome.

As for Ukraine, outcome 2 is a rational outcome because Ukraine would prefer this outcome to any other outcome where both Russia and NATO’s actions would remain unchanged. Since rational outcomes are also stable, then Ukraine would not make any unilateral improvements.

Lastly, NATO does have a potential UI from outcome 4 to outcome 0 and this is because NATO would rather not exhaust resources on peace options if Russia is going to annex Ukraine anyways. As was the case with Russia, the outcome becomes stable since the UI could result in a consistent improvement by other players that would make NATO worse off. With this in mind, NATO would rather remain with their original payout in outcome 4 instead of shifting to outcome 0.

The most likely outcome (equilibria) is the outcome that is stable for each player in the game meaning that any column composed of an “s” or “r” for each player would therefore be an equilibria. In this specific game, the highlighted column is the one outcome that possesses stability because outcome 5 is stable for Russia, outcome 2 is rational for Ukraine, and outcome 4 is stable for NATO. This equilibrium is denoted by an “E” while the others are marked by an “x” symbolizing non-stable outcomes.

RESULTS

Recall from the extensive form game that the path of play was (HA,DI,NT) which also equates to the outcome of (1,1,1). This corresponded to a predicted outcome where Russia would seek to annex Ukraine, who would then choose to offer diplomacy and strive for independence all the while NATO tries to negotiate a treaty. The following equilibria from the metagame analysis consisted of outcome 5/(1,0,1) for Russia, outcome 2/(0,1,0) for Ukraine and outcome 4/(0,0,1) for NATO. Of all the possible equilibria outcomes, only one can eventually occur, and only time will tell which outcome that might be.

It is interesting to note that both the extensive form game and metagame analysis algorithm led to different results. Although outcome 7 was the equilibria in the extensive game, it remained as an unstable outcome for Russia in the MA which resulted in an overall unstable outcome. This differentiation between the games results in 4 possible outcomes to the Russia - Ukraine conflict which is out of the 64 total outcomes (2^6 = 64) that were possible from this specific condensed game. Although there isn't one definite prediction from both games, 4 out of 64 potential outcomes still provides a much better insight to how the conflict might conclude when considering how many possible outcomes there truly are.

CONCLUSION & SCOPE OF FUTURE WORK

Earlier pages mention that this capstone project serves the two fold purpose of not only predicting feasible outcomes for the Russia and Ukraine war, but also filling in an apparent gap in the field where extensive form games haven't been combined with the metagame analysis algorithm. Now with the benefit of hindsight, it is somewhat clear as to perhaps why extensive form games and the MA remain separate. A key difference between extensive form games and the metagame analysis algorithm is that the extensive approach looks at sequential actions while the MA looks at simultaneous actions. In doing so, the MA weighs possible threats to adjust equilibria and stable outcomes, while failing to account for which threats may or may not be credible. In other words, the MA lacks a way to calculate uncertainty, while extensive form games do offer a way to do so (although that specific uncertainty calculation was omitted in this game). Uncertainty could be about the resolve of western nations to support Ukraine or the implications of western politicians suggesting they are not fully behind Ukraine. Either way this differentiation between the approaches would result in varied outcomes in a more complex game, but have also resulted in varied outcomes even in this condensed game. None of this is to say that because of the varied outcomes between the approaches then the impact of the project is lessened, since that simply isn't the case. Rather both the objectives of the project were completed, and done so in a way that helps to provide understanding for why the metagame analysis algorithm may not be as developed in the field of political science as extensive form games are.

In many ways, there remains space for the further improvement of this particular game, but the condensed nature of the game made sure of that from the very onset. Gaps in uncertainty calculations or simultaneous stability calculations leave some things to be desired, but perhaps this particular project must remain unfinished because the conflict it studies is also. In the meantime there are predictions worth reflecting upon, insights worth remembering, and questions that can only be answered through the continuation, or hopefully culmination of the war at hand.

Peace is a choice, and although political game theory might provide some insights as to how to get there, it seems fair to say that studying a conflict can never spontaneously create peace, but only point players in the right direction. Game theory has brought us to the cliff's edge, and what's left of the journey remains in the hands of humanity who can firmly pursue a bridge of charity or be stunted by a fall of bloodshed. May those hands work relentlessly towards change and work to favor our undertaking as we seek a just and lasting peace for all nations.

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