

# Modeling Shakespeare's *Romeo and Juliet* as a Sequential, Strategic Game

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A Look at Nash Equilibria and Preference Sensitivity

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## Introduction

“Two households, both alike in dignity, /In fair Verona, where we lay our scene, /From ancient grudge break to new mutiny, /Where civil blood makes civil hands unclean. /From forth the fatal loins of these two foes /A pair of star-cross'd lovers take their life; /Whose misadventured piteous overthrows /Doth with their death bury their parents' strife. /The fearful passage of their death-mark'd love, /And the continuance of their parents' rage, /Which, but their children's end, nought could remove, /Is now the two hours' traffic of our stage; /The which if you with patient ears attend, /What here shall miss, our toil shall strive to mend” (Shakespeare, lines 1-14).

The passage written above is the entire prologue, or summary if you will, from Shakespeare's tragic play, *Romeo and Juliet*. As can be read, the play tells the tale of two young lovers from separate families who simply weren't meant to be together due to their parents' family feud. However, in the end, they find a way to be together still, even if the only way is in death. It is these two lovers who will become the “players” in our sequential, strategic game model and analysis. Therefore, it is the choices of Romeo Montague and Juliet Capulet that will be used to create the extensive game tree model. Due to the length of the play, only those choices which have a significant impact on the ending of the play will be considered since they are the most pertinent to what we are trying to model. For Romeo these choices will include: going to the Capulet party or not (Act 1, Scenes 2-4), whether or not he will formally propose marriage to Juliet (Act 2, Scene 3), killing Tybalt or not (Act 3, Scene 1), accepting his sentence of being exiled or being executed for his crimes (Act 3, Scene 3), deciding to return to Verona or not (Act 5, Scene 1), and if he does return, will he drink poison or not (Act 5, Scene 3). Juliet's critical choices include: consenting to see Romeo again or not (Act 2, Scene 1), accepting or rejecting Romeo's marriage proposal (Act 2, Scenes 4-5), marrying Paris or not (throughout the whole play), whether or not to seek the Friar's help (Act 3, Scene 5), drinking the herbal “potion” or not (Act 4, Scene 3), and whether or not to commit suicide if things don't proceed as she desires or is planned (Act 3, Scene 5 and Act 4, Scene 3 and Act 5, Scene 3).

In order to accurately model the players' level of satisfaction with the outcomes of each different possible combination of the above choices, the players must also have motivations or

preferences guiding them through their decisions. Therefore, we will assign to Romeo a preference set such that his primary preference is to be with Juliet, his secondary preference is to be loyal to his friends and family, his tertiary preference is to follow the law, and his quaternary preference is to be alive. Juliet must also have her own motivations; her preferences will be assigned such that her primary preference is to be with Romeo, her secondary preference is to not marry Paris, her tertiary preference is to be courageous and use all available options to solve her problems, and her quaternary preference is to be alive along with other Capulet family members. Both of these preference sets and the order in which they are listed were decided based on the characters of the play and what motivations they seem to have or mention more than others throughout Shakespeare's actual text. It is clear that both characters truly want to be together otherwise they wouldn't go through everything they do, which dictates their primary motivations. Romeo is willing to fly in the face of the law in order to kill Tybalt to revenge his best friend which clearly makes his friends and family only second to Juliet, and he does accept the Prince's sentence of exile over execution because staying alive is also important to him. Juliet makes her disdain for marrying Paris known in Act 3, Scene 5 when she says, "He shall not make me there a joyful bride./... /I pray you, tell my lord and father, madam,/I will not marry yet; and, when I do, I swear,/It shall be Romeo, whom you know I hate,/Rather than Paris. These are news indeed!" which is only second to how much she wants to be with Romeo (Shakespeare, lines 117-123). In addition, Juliet also seems to place value on exhausting all options to get her "fairy tale" ending by seeking the help of Friar Lawrence and taking his herbal "potion". In Act 4, Scene 1 it is clear that she is even willing to kill herself to solve the problem when she says, "Tell me not, friar, that thou hear'st of this,/ Unless thou tell me how I may prevent it:/ If, in thy wisdom, thou canst give no help,/Do thou but call my resolution wise,/And with this knife I'll help it presently./... /Be not so long to speak; I long to die,/If what thou speak'st speak not of remedy" (Shakespeare, lines 50- 55 & 66-67). It is these preference orderings that will decide the ordinal payoffs for each branch of the extensive game tree that

will now be described and analyzed.

### **Game Tree Discussion and Analysis**

In order to model *Romeo and Juliet* as a sequential, strategic game, the method of designing an extensive game tree was used where each branching represents a different choice that could be made by the character whose choice it is. Juliet's choices are denoted by a pink coloring and Romeo's are indicated by a blue coloring in the actual model. The order of the choices being made follows the order that they occur in the actual play. Some branches have also been added in for Juliet along the way due to the fact that she can choose to marry Paris and/or whether or not to commit suicide at numerous points in the story. Information sets are also a crucial part of this model due to the fact that there are certain times in the play that Romeo makes choices without knowing what Juliet has chosen to do preceding this choice. Romeo's nontrivial information set includes the choice that he makes about whether or not to come back to Verona. Since he's been out of the city for some length of time and the only means of communication that he could have had with either Juliet or the Friar would have been by telegram, he is completely unaware of the plan they deduced to fix the situation of her being forced to marry Paris in Romeo's absence. Therefore, he makes his choice to return entirely based on the rumor of Juliet's death rather than knowing all the facts. The full game model can be found in the Appendix, labeled as Figure 1.

From here it would seem prudent to discuss the ordinal payoffs assigned to each possible outcome that the game tree shows, keeping in mind that the model is incomplete because it cannot be expanded at all without additional information regarding the other possible outcomes. Below is a table depicting all of the ordinal payoff pairs with their corresponding outcomes for each branch of the extensive game tree, however, each player's best and worst outcomes will be discussed further below the table. The table is arranged such that it follows first Romeo's and then Juliet's ordinal values.

Ordinal Payoff Pair	Associated Outcomes
(7, 18)	Romeo and Juliet are married, Tybalt is dead, the Friar helps Juliet, and Romeo and Juliet are both dead
(7, 17)	Romeo and Juliet are married, Tybalt is dead, the Friar helps Juliet, and only Romeo is dead
(7, 16)	Romeo and Juliet are married, Tybalt is dead, the Friar helps Juliet, Juliet commits suicide and so does Romeo
(7, 14)	Romeo and Juliet are married, Tybalt is dead, the Friar helps Juliet, Juliet marries Paris, and Romeo dies
(7, 13)	Romeo and Juliet are married, Tybalt is dead, the Friar doesn't help Juliet, Juliet commits suicide and so does Romeo
(7, 11)	Romeo and Juliet are married, Tybalt is dead, the Friar doesn't help Juliet, Juliet commits suicide and Romeo is alive in Verona
(6, 19)	Romeo and Juliet are married, Tybalt is dead, the Friar helps Juliet, and both of them are alive together
(6, 16)	Romeo and Juliet are married, Tybalt is dead, the Friar helps Juliet, Juliet commits suicide and Romeo is alive in Verona
(6, 15)	Romeo and Juliet are married, Tybalt is dead, the Friar helps Juliet, Juliet marries Paris and Romeo is alive in Verona
(6, 13)	Romeo and Juliet are married, Tybalt is dead, the Friar doesn't help Juliet, Juliet commits suicide and Romeo is alive in Verona
(6, 12)	Romeo and Juliet are married, Tybalt is dead, the Friar doesn't help Juliet, Juliet marries Paris and Romeo is alive in Verona
(5, 10)	Romeo and Juliet are married, Tybalt is dead, the Friar helps Juliet, but Romeo doesn't come back
(5, 9)	Romeo and Juliet are married, Tybalt is dead, the Friar helps/doesn't help Juliet, Juliet commits suicide and Romeo doesn't come back
(5, 8)	Romeo and Juliet are married, Tybalt is dead, the Friar helps Juliet, Juliet marries Paris and Romeo doesn't come back
(5, 7)	Romeo and Juliet are married, Romeo kills Tybalt, Romeo flees but doesn't return and Juliet marries Paris
(4, 6)	Romeo and Juliet are married, Romeo kills Tybalt, Romeo is executed, and Juliet commits suicide
(4, 5)	Romeo and Juliet are married, Romeo kills Tybalt, Romeo is executed, and Juliet marries Paris
(3, 4)	Romeo and Juliet are married, but Tybalt kills Romeo in the brawl
(2, 3)	Juliet rejects Romeo's marriage proposal and doesn't marry Paris
(2, 2)	Juliet rejects Romeo's marriage proposal and marries Paris
(1, 1)	Romeo goes to the party, they make plans to meet again, but he never proposes
(1, 0)	Romeo goes to the party but she blows him off
(0,0)	Romeo and Juliet never meet

As can be seen, Romeo's character has numerous best possible outcomes because they include all the instances where he goes to the party, proposes to Juliet, kills Tybalt, leaves the city in exile, returns to the city, and then drinks the poison, with an end result of Romeo and Juliet being married,

Tybalt being killed by Romeo, and both Romeo and Juliet being dead at their own hands. This outcome is the best because it follows his assigned preference order the closest. If he wants to be with Juliet then he must go to the party to even meet her, and he must also propose to her in order to continue being with her romantically. From here we can use his primary and secondary preferences to decide that it would be better for him if he kills Tybalt to revenge his best friend Mercutio because being loyal to his family and friends ranks higher than following the law, and if he doesn't kill Tybalt, then Tybalt will kill him which would take him away from being with Juliet. For his next choice we need to remember that following the law and being alive in order to be with Juliet are important to him so he must choose to leave the city over staying and being executed. He should then choose to return to the city again because being with Juliet outranks following the law. And finally, choosing to drink the poison is a better option than not drinking it because the only possible way he can be with Juliet in any of the situations including this branch is in death and being with her outranks being alive. These outcomes were all assigned an ordinal payoff of 7.

Romeo's second best ranking outcomes are those where he goes to the party, proposes to Juliet, kills Tybalt, leaves the city in exile, returns to the city, and then doesn't drink the poison resulting in the final outcome where the two characters are married, Romeo kills Tybalt, and either both characters are living or only Juliet is dead depending on the branch; these outcomes have been assigned an ordinal payoff of 6. This outcome sequence follows the exact same logic as his best possible option except that for his final choices he will want to return to the city to be with Juliet since that preference outranks following the law, but this time drinking the poison is no longer an option because it's already been ascribed a value so not drinking the poison is the second best option for him based on this logic. In this outcome there is also still the hope that he can be with Juliet.

The third best option for Romeo is where he goes to the party, proposes to Juliet, kills Tybalt, leaves the city in exile, and simply doesn't come back to Verona. In this situation the final outcome is

such that Romeo and Juliet are married, he kills Tybalt, either both characters are living or only Juliet is dead depending on the branch, and Romeo is still in exile. This outcome has the ordinal payoff of 5 because for him, it is still better to kill Tybalt than not to kill Tybalt due to his primary and secondary preferences which will lead him to his choice of leaving the city or being executed in which he would still want to choose leaving the city because of his primary, tertiary, and quaternary preferences. This leaves him with only the option of not returning since the other options already have ascribed values. Again, in this option hope still remains for Romeo that he may still be reunited with Juliet.

The fourth best outcome for this player is the one where he goes to the party, proposes to Juliet, kills Tybalt, and then is executed which produces the final outcome of the lovers being married, Romeo killing Tybalt and being executed while Juliet is still living. This outcome is ranked fourth because Romeo's primary preference is to be with Juliet so he will make his first two choices based on that preference. For his choice of killing Tybalt or not we must look at his primary, secondary and tertiary preferences. Since he would rather kill Tybalt to revenge his best friend than follow the law and die himself, which would surely take him further away from his primary goal of being with Juliet then it is still better for him to kill Tybalt and be executed than not to kill Tybalt at all thus earning this outcome an ordinal payoff of 4.

This leads us to Romeo's worst four options. The best of the four is the one where he goes to the party, proposes to Juliet, and doesn't kill Tybalt. This outcome follows his primary preference of being with Juliet since he goes to the party and then proposes marriage to her, but because the option to kill Tybalt has already been ascribed values then he must choose not to kill Tybalt, in which case Tybalt will kill him. But, his character will have followed his primary motivation up until that choice producing the overall outcome of him and Juliet being married, but Tybalt is still living, earning Romeo an ordinal payoff of 3. The next worst option is the one where Romeo goes to the party and proposes to Juliet, but she rejects his proposal which means that they never get married. But for Romeo, it is better

to have loved and lost than not loved at all. He will have been following his primary motivation, but the choice to accept or reject the proposal was hers, giving him an ordinal payoff of 2. The next lowest ranked outcome has two possible branches: the one where Romeo goes to the party and then doesn't propose, and the one where he goes to the party but she blows him off. In either case, we get the outcome that their relationship goes no farther than that one night together which earns him an ordinal payoff of 1. And the worst possible option for Romeo is to not even go to the party. If he chooses this option he is violating his primary preference because there will be no way for him to meet Juliet and he'll stick to loving Rosalind who doesn't love him back (Act 1, Scene 1) which earns him a payoff of 0.

Having thoroughly examined Romeo's potential outcome rankings, we now turn our attention to the same situations from Juliet's perspective. Her best possible option earns her an ordinal payoff of 19 and it follows the sequence such that she makes plans to see him again, accepts his proposal, seeks help from the Friar, drinks the herbal "potion" he gives her, and Romeo returns but doesn't drink the poison. The outcome of this sequence is such that the two characters are married, Romeo kills Tybalt, the Friar helps her, and both characters are together and alive. The reason that this outcome is the best for Juliet is because making plans with Romeo and accepting his marriage proposal follow her primary preference. And when she must decide whether or not to seek help from the Friar she will use her primary and tertiary preferences to guide her choice such that she asks him for help. She will also proceed to drink the potion because of her primary, secondary, and tertiary preferences that tell her to do whatever it takes to be with Romeo and not have to marry Paris. And if Romeo returns to Verona and doesn't poison himself then they can be together as planned which is her ultimate goal.

Juliet's second best option is the one where she makes plans to see Romeo again, accepts his proposal, seeks help from the Friar, drinks the herbal "potion" he gives her, Romeo returns and drinks the poison, and then she kills herself. With this sequence the final outcome is such that the two characters are married, Romeo kills Tybalt, and both characters are together, but in death. The logic for



this situation is similar to that of her best option, but it takes into account the fact that Romeo could have instead chosen to drink the poison upon his arrival to her tomb. In this case, her primary preference would have already guided her to choose to drink the potion and then to choose killing herself so that she could still be with him in death if she couldn't be with him in life, giving her an ordinal payoff of 18.

Juliet's third best option is the one where she makes plans to see Romeo again, accepts his proposal, seeks help from the Friar, drinks the herbal "potion" he gives her, Romeo returns and drinks the poison, and then she doesn't kill herself. With this sequence the final outcome is such that the two characters are married, Romeo kills Tybalt, Romeo is dead, but Juliet is still alive. The logic for this situation is again similar to that of her best option, but it will again take into account the fact that Romeo could have instead chosen to drink the poison upon his arrival to her tomb. In this case, her primary preference would guide her to want to drink the potion over not drinking the potion and also want Romeo to return to Verona. But because the choice of killing herself already has an ascribed value then she must choose not to kill herself and receive an ordinal payoff of 17.

Her fourth best option is the one where she makes plans to see Romeo again, accepts his proposal, seeks help from the Friar, doesn't drink the herbal "potion" he gives her, she commits suicide, and Romeo returns to Verona. With this sequence the final outcome is such that the two characters are married, Romeo kills Tybalt, Juliet has seen the Friar, Juliet kills herself, and Romeo is back in Verona but may or may not be dead depending on the branch. The reasoning behind this sequence is that seeking the Friar's help is still better than not talking to anyone based on her primary and tertiary preferences, and since she wants to be with Romeo, we must disregard the option where she takes the potion and he still doesn't come back to Verona for her. Therefore we will look instead at the branch where she doesn't drink the potion. Since neither option will truly allow her to be with Romeo then we must examine her secondary preference which is to not marry Paris. This preference outranks her quaternary

preference to be alive. Therefore she will select suicide over marrying Paris, but because she is already dead before Romeo makes his choice then her ordinal payoff of 16 is the same whether or not he drinks the poison after returning to the city. This is because it would still be safe to assume that even in death she would want him to return to Verona to satisfy her primary preference.

This character's fifth best option is the one that follows the sequence in which she makes plans to see Romeo again, accepts his proposal, seeks help from the Friar, doesn't drink the herbal "potion" he gives her, she marries Paris, and Romeo returns to Verona but he doesn't drink the poison. With this sequence the final outcome is such that Romeo and Juliet are married, Romeo kills Tybalt, Juliet has seen the Friar for help, she marries Paris, and Romeo is alive in Verona. The reasoning behind this sequence is similar to that of the last one. Since she sees the Friar but doesn't drink the potion then neither option will truly allow her to be with Romeo, but her option to commit suicide has already been ranked. Therefore she will select to marry Paris, but because she publically marries Paris then her ordinal payoff is 15 if Romeo doesn't drink the poison. The reason for this piece of logic is that if she marries Paris then there is no real way she can ever be with Romeo again due to society's standards at that time, but having him return to the city and not drink the poison follows her primary preference of wanting to be with him. Also, there is no information about how the play would have proceeded if she had instead married Paris to be able to have her decide anything further.

Her next worst option is one where she makes plans to see Romeo again, accepts his proposal, she seeks help from the Friar but doesn't drink the potion, she marries Paris, and Romeo returns to Verona to drink the poison. With this sequence the final outcome is such that the two characters are married, Romeo kills Tybalt, Juliet marries Paris, and Romeo is dead. The judgment behind ranking this sequence next is that she would want Romeo to leave the city instead of being executed in the hopes that they could be reunited. Therefore she must choose whether or not to see the Friar and her preferences would indicate that she would seek his help. And similarly to the last option having Romeo

come back is better than having him stay in exile so we will examine the branch where she doesn't drink the potion. Since neither option will truly allow her to be with Romeo then her secondary preference to not marry Paris would outrank her quaternary preference to be alive. Therefore she would select suicide over marrying Paris, but because we have already assigned values for that ending then she must choose to marry Paris and have Romeo drink the poison giving her an ordinal payoff of 14.

Juliet's seventh best option is one where she makes plans to see Romeo again, accepts his proposal, she doesn't get help from the Friar, she commits suicide, and Romeo returns to Verona. With this sequence the final outcome is such that the two characters are married, Romeo kills Tybalt, Juliet kills herself, and Romeo may or may not be dead. This outcome is ranked next because Juliet would want to see the Friar and have Romeo return according to her preferences, but we've already examined that branch so we must now examine the branch where she doesn't consult the Friar. Similarly to the other option where she commits suicide, since neither option will truly allow her to be with Romeo then we must consider her secondary preference to not marry Paris which outranks her quaternary preference to be alive. Therefore she would select suicide over marrying Paris and since she dies prior to Romeo's choice being made the values for that ending both give her an ordinal payoff of 13.

Juliet's next worst option is the one where she makes plans to see Romeo again, accepts his proposal, she doesn't get help from the Friar, marries Paris, and Romeo returns to Verona but doesn't drink the poison. With this sequence the final outcome is such that the two characters are married, Romeo kills Tybalt, Juliet kills herself, and Romeo is alive in Verona. This outcome is ranked next worst for similar reasons as the above outcome. And because we've already assigned values for when she commits suicide then she must instead choose to marry Paris. But because she would still want the slight glimmer of hope to be with Romeo, no matter how impossible it is, she would rather him not drink the poison giving her an ordinal payoff of 12.

Juliet's next worst option available is the complement to the last one in which she makes plans

to see Romeo again, accepts his proposal, she doesn't get help from the Friar, marries Paris, and Romeo returns to Verona to drink the poison. With this sequence the final outcome is such that the two characters are married, Romeo kills Tybalt, Juliet kills herself, and Romeo dies in Verona. This outcome is ranked next worst for some of the same reasons as the last couple outcomes. And similarly to the last one, since we've already assigned values for when she commits suicide then she must instead choose to marry Paris. But because we have already given a rank to the situation where he does not drink the poison then this time Romeo must drink it which gives her an ordinal payoff of 11.

Now we must return to the upper branch of the tree to examine the outcomes where Romeo simply doesn't come back to Verona. Juliet's next four descending options available are assigned the ordinal values of 10, 9, 8, and 7 respectively. The situation assigned a value of 10 is the one where she makes plans to see Romeo again, accepts his proposal, she gets help from the Friar, she drinks the potion, and Romeo doesn't return to Verona. With this sequence the final outcome is such that the two characters are married, Romeo kills Tybalt, Juliet sees the Friar and takes the potion, but Romeo never returns to Verona as far as we know. This outcome and the ones following are worse than the last ones because Juliet's primary preference is to be with him, but by him choosing not to return they must fall lower on the list than all of the situations in which he does return because then there really is no chance of them being together again as far as we know. The next two outcomes are such that she makes plans to see Romeo again, accepts his proposal, she gets help from the Friar but she doesn't drink the potion or she doesn't get his help at all, she commits suicide, and Romeo doesn't return to Verona. These outcomes are both valued at 9 because they are essentially the same outcome in which they get married, he kills Tybalt, she kills herself, and he never returns to Verona. This outcome is only better than the next two outcomes because her secondary preference to not marry Paris outranks her preference to be alive so she would choose to kill herself rather than marry Paris. The outcomes valued at 8 and 7 are similar because their end result is the same, but in the outcome valued at 8 Juliet sees the

Friar and in the one valued at 7 she does not. These are such that she makes plans to see Romeo again, accepts his proposal, she gets help from the Friar (valued at 8) but she doesn't drink the potion or she doesn't get his help at all (valued at 7), she marries Paris, and Romeo doesn't return to Verona.

To find her next worst option we must look back at Romeo's choice of whether or not to flee the city or be executed. Since Romeo will want to kill Tybalt and Juliet would rather lose Tybalt than Romeo, we will in fact arrive at this choice. Having examined all the outcomes when Romeo chooses to leave the city we can now look at the outcomes for when he instead chooses execution. In this situation she will have already made plans with him, accepted his proposal, and Romeo will have killed Tybalt, but chosen execution. After Romeo is dead, which we can assume will happen if the Prince keeps his word, then Juliet would most likely be left again with the decision to marry Paris or commit suicide. Because her primary preference is to be with Romeo and she would rather die than marry Paris according to her secondary and quaternary preferences then she will choose to commit suicide for an ordinal value of 6 followed by marrying Paris for an ordinal value of 5.

Backing up even further in the tree, we can see that her fourth ordinal valued option occurs when she makes further plans with Romeo and accepts his proposal, but Romeo is instead killed by Tybalt because he didn't kill Tybalt in the brawl. This leaves Juliet with an outcome where she and Romeo were married, but she is now a very young widow with her cousin to blame for it. Her primary preference would have led her to this point, but it was Romeo's decision not to kill Tybalt that caused it to be valued as low as it is.

Juliet's next worst options occur when she makes plans with Romeo, but rejects his proposal and either consents to marry Paris (valued at 3) or not (valued at 2). This leaves Juliet with outcomes such that she and Romeo never marry due to her decision, but she must choose to marry Paris or not. She will choose to not marry Paris over marrying him because of her secondary preference. These outcomes would seem to violate her primary preference that she wants to be with Romeo but not as

much as the following worst options because the subject of marriage was broached which is better than blowing him off in the first place. Should the lovers make plans, but Romeo never proposes then it is his fault that Juliet cannot follow her primary preference of being with him, thus giving her an ordinal payoff of 1. And the worst possible options for Juliet are when Romeo comes to the party and she blows him off or he just doesn't come to the party thereby eliminating the chance of meeting her. For both of these outcomes an ordinal value of 0 has been assigned because if either of them choose these options then they are both violating their primary preferences of being together because there will be no way for him to meet Juliet and she'll likely be forced to marry Paris to make her parents happy.

Having established the structure of the extensive game tree and the ordinal payoff values, we next analyzed the game tree to find the Nash Equilibria for this model of *Romeo and Juliet*. Using the online open source program called "GAMBIT," we input the entire game tree and ran an equilibrium test on the extensive game. The program found that the only Nash Equilibrium possible for this model had a payoff pair of (7, 18) for Romeo and Juliet respectively. This corresponds to the sequence where Romeo goes to the party, she makes plans with him, he proposes to Juliet, she accepts his proposal, he kills Tybalt and leaves the city in exile, she sees the Friar for help and drinks the potion, he then returns to the city, drinks the poison, and she kills herself out of anguish. Surprisingly, this is the exact same sequence that Shakespeare's play follows ending with an outcome where Romeo and Juliet were secretly married, Tybalt was slain by Romeo, and both main characters end up committing suicide in order to be together. A Nash Equilibrium analysis was also performed by hand on the strategic game to double check our results, and it resulted in finding the exact same payoff pair as the only possible Nash Equilibrium for this model. This would suggest that the model in question is a strong enough representation of Shakespeare's actual plot.

It also seemed appropriate to look at a reduced version of this game since we can accurately do a small bit of backward induction on our game tree. This new model can be seen in the Appendix

labeled as Figure 2. The changes that have been made are such that the node labeled 2:3 for Juliet was assigned the ordinal payoff pair of (2, 3) instead of allowing her another choice since she will always choose the higher of the two payoffs. In the same way, Juliet's node 2:9 was reduced to a (4, 6) ordinal payoff pair and 2:6 was reduced to a (7, 18) ordinal payoff pair. Then we looked at where we could reduce things for Romeo while still being sensitive to the location of his information set. Therefore we were able to reduce node 1:6 to be (7, 18), node 1:7 to be (7, 14), node 1:8 to be (7, 16), node 1:9 to be (7, 11), and node 1:10 to be (7, 13). Again, both "GAMBIT" and the "by hand" methods were used to run a Nash Equilibrium analysis of our reduced game tree. We got the result that the only possible Nash Equilibrium for this model was the ordinal payoff pair (7, 18) once again.

### **Discussion of Preference Sensitivity**

Another point of interest for this project comes from the notion of changing and switching around the rankings of the motivations/preferences for either one or both characters to see how important the ordering is to achieving Shakespeare's ending of the play as the Nash Equilibrium. Since each player has a total of four ranked preferences then there are 24 total possible ranked combinations of those preferences. However, not all of those 48 combinations will be of interest to us due to the fact that they will have limitations that prevent the characters from ever reaching that part of the game tree. First we will take a look at Romeo's potential preference ranking combinations. Clearly, our original ranking for him will result in the same ending we found in the original model; this will be important for comparison with the other 23 combinations. One of the first things we realized is that in any of Romeo's preference combinations where his loyalty to his family and friends ranked higher than his desire to be with Juliet then he won't ever propose to her and therefore should be removed from the list of possibilities. Another pertinent insight is such that when Romeo's need to follow the law is ranked higher than his feeling of loyalty to his family and friends then he won't kill Tybalt and will instead be

killed himself thus restricting his potential payoffs. All of the combinations where this is true must therefore also be removed from the list of possibilities. And finally, when his desire to stay alive outranks his desire to be with Juliet then he won't ever choose to drink the poison so that they can be together in death. In addition to this, he may also not even choose to return to Verona depending on the ordering. Each case where these rankings are seen must also be eliminated if we are to potentially achieve the same ending. After numerous rounds of elimination we are left with the possibilities below.

<b>Primary: Being with Juliet, Secondary: Loyalty to family and friends, Tertiary: Following the law, and Quaternary: Being alive</b>
<b>Primary: Being with Juliet, Secondary: Loyalty to family and friends, Tertiary: Being alive, and Quaternary: Following the law</b>
<b>Primary: Being with Juliet, Secondary: Being alive, Tertiary: Loyalty to family and friends, and Quaternary: Following the law</b>

Now we will do the same thing for Juliet's preference rankings. Similar to the realizations we made for Romeo, we also realized that for any of Juliet's preference combinations where her desire to be alive is ranked higher than her determination not to marry Paris then she will in fact marry Paris instead; these combinations should therefore be removed from the list of possibilities. Another pertinent insight is such that when Juliet's desire to be alive along with the other Capulet family members is higher than her desire to utilize all possible solutions then she won't even consider drinking the potion and may not even see the Friar depending on the ordering. All of these combinations must also be removed from the list of possibilities. When her desire to utilize all possible solutions outranks her desire to be with Romeo, her first few choices may also not be clear enough to evaluate so each case where this ranking is seen must also be eliminated if we are to potentially achieve the same ending. It would also make no sense to have her ranking of being with Romeo last in the sequence for the same reason. After numerous rounds of elimination we are left with the possibilities in the table below.

<b>Primary: Being with Romeo, Secondary: Not marrying Paris, Tertiary: Using all possible options to find a good solution, and Quaternary: Being alive</b>
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Primary: Being with Romeo, Secondary: Using all possible options to find a good solution, Tertiary: Not marry Paris, and Quaternary: Being alive
Primary: Not marrying Paris, Secondary: Being with Romeo, Tertiary: Using all possible options to find a good solution, and Quaternary: Being alive
Primary: Not marrying Paris, Secondary: Using all possible options to find a good solution, Tertiary: Being with Romeo, and Quaternary: Being alive

For means of analysis, each set of feasible rankings for both Romeo and Juliet was tested with each other in the game tree. The results showed that more often than not, pairing any of the above motivation lists, such that there is one for each player, will result in the same Nash Equilibrium. Perhaps this is due to the fact that in the full model's strategic game there are numerous pure strategy pairings that can lead to the Nash Equilibrium payoff, but further analysis would be needed to verify this.

Another way to analyze and look at the sensitivity of the player's preference ranking is to look at a subgame of the full model that is critical to the Nash Equilibrium outcome. The subgame of interest for our case begins at Juliet's decision to either seek Friar Lawrence's help or not, which is located at the node 2:4. Because we already know that we can reduce the extensive game tree to help us with backward induction we will again use this technique to examine the reduced subgame starting at node 2:4. It is clear that in this case we are looking at the situation of a 2 X 5 strategic game because Romeo only has two possible strategies at this point while Juliet has five. The reduced subgame tree and strategic game chart are located in the Appendix labeled as Figure 3 and Figure 4 respectively. Once again, "GAMBIT" was used to run a Nash Equilibrium test on the extensive game tree which gives us the payoff pair of (7, 18), our same Nash Equilibrium from the full extensive model. This means that we can essentially assign that payoff pair to the 2:4 node, which will allow us to perform backward induction on the full game tree model. Again, we find that the ordinal payoff pair (7, 18) will be chosen at all points along the tree where a choice must be made because both values will always be greater than the other payoff pairs'. Therefore we can conclude that the payoff pair (7, 18) is in fact our Nash Equilibrium for this model of Shakespeare's *Romeo and Juliet*.

## References and Resources

McKelvey, Richard D., McLennan, Andrew M., and Turocy, Theodore L. (2010). Gambit: Software Tools for Game Theory, Version 0.2010.09.01. <http://www.gambit-project.org>.

Shakespeare, William. "Romeo and Juliet." From *The Complete Works of William Shakespeare, Vol II*. Ed. David Bevington. New York: Bantam Books, 1988. Print.

# Appendix

Figure 1: Full Game Tree Model with Ordinal Payoff Pairs

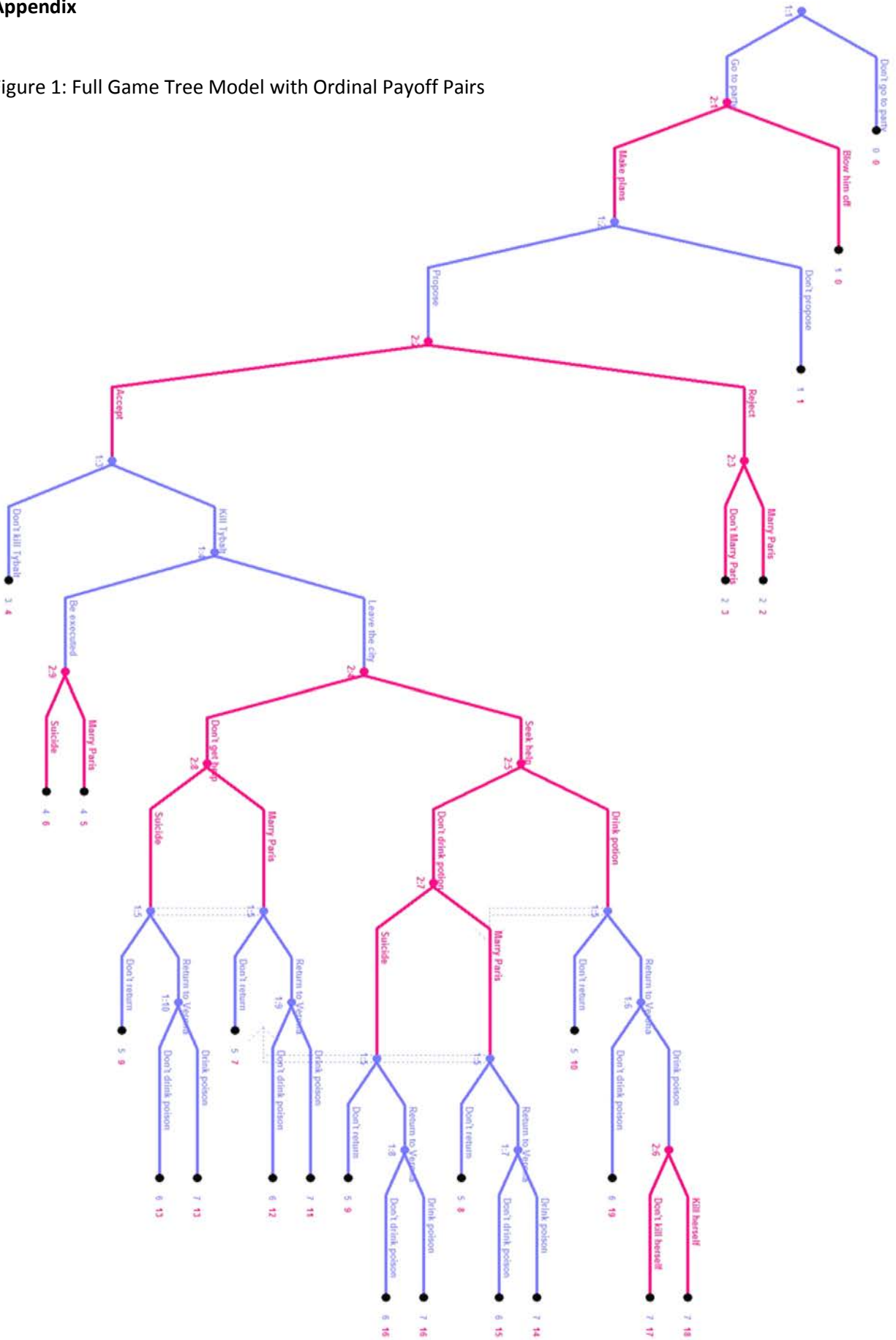


Figure 2: Reduced Game Tree Model

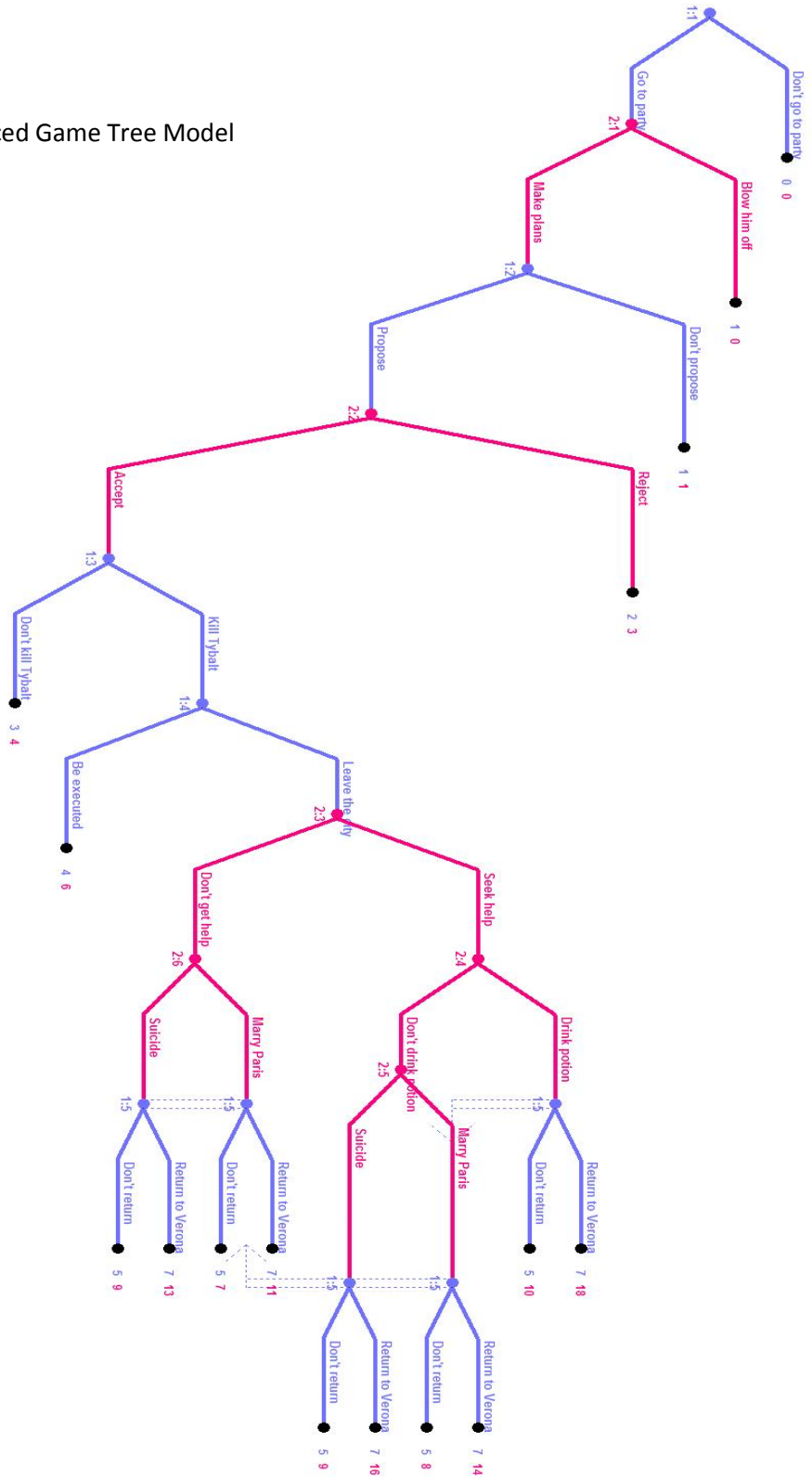


Figure 3: Sensitivity Sub-game Tree

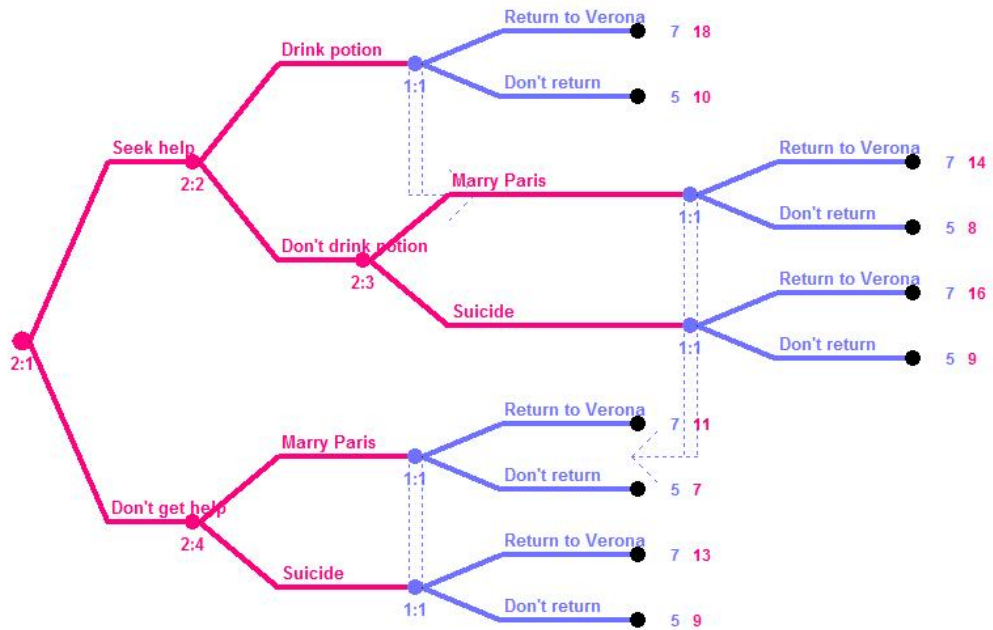


Figure 4: Sensitivity Strategic Game

	11**	121*	122*	2**1	2**2
1	7 18	7 14	7 16	7 11	7 13
2	5 10	5 8	5 9	5 7	5 9

## Project Self Evaluation

### Strengths:

- Throughout the entire process of completing this project I tried to really take the time to get to know my “players” by rereading large portions of the actual play. For me it was important to try to get inside their heads. To try to feel what they felt and understand their motivations. This was the key to figuring out my preference ranking system for each individual character.
- Another strength I feel that certainly aided me along the way with this project was the ability to ask questions of both my peers and the professor. It definitely helped to have both Ruthi and Erin check over my model, even though they both saw it at different stages in the process. They were also great to bounce ideas off of for educated feedback. The help of the professor was also critical to being able to push this project to another level up. The constant feedback and guidance only made the end product that much stronger.

### Weaknesses/ Areas for Improvement:

- One area for improvement that I noticed along the way is my ability to understand where information sets are appropriate. At first, I had two information sets in my model such that Juliet also had one on her very last choice that was later omitted from the final game tree. The ability to have seen that mistake earlier on in the process would have saved me some time and would have been problematic if it had never gotten fixed. More practice with using this concept would help I’m sure.
- Another weakness I saw for myself during this process was the ability to have an end goal. I had already selected my subject and how I was going to model it, but I had no real end goal for where I wanted my project to head. I was much more concerned about the details than the big picture. However, this is one area that I believe I can keep working at and improving with each new project I do.