CIS 730: Intro to Artificial Intelligence Final Project: Clue AI

James Wensel
Kansas State University
jdwensel@ksu.edu

Abstract

The goal of this project was to create an AI that can play the board game Clue. Clue is a game based on making deductions based on information shown both to the player and to the opponents of the player. These deductions are used to information all the actions taken during the rest of the game. The Clue AI is not only able to complete the deductions necessary to play the game Clue, it is also able to use all this information to inform all other actions necessary to play Clue.

Background

The game of clue is a very simple game. There are 21 cards in the base game, 6 people cards, 6 weapon cards, and 9 rooms cards, and there is exactly one of each card in the game. 3 Cards are selected, 1 person, 1 weapon, and 1 room, as the murder situation. The rest of the cards are then randomly distributed to each player. During a player's turn, they roll dice to determine how far they car move and attempt to enter a room on the game board. If a player ends their turn in a room, they are able to make a suggestion. These are essentially an "educated guess" as to what cards may be in the center, 1 person, 1 weapon, and 1 room, with the room being required to be the room the player is currently in. The suggestion then passes to the person to the immediate left of the turn player, and if they have any cards in the suggestion, they are required to show the turn player exactly one card from the suggestion to disprove it, but no other players are allowed to see the card. Play like this continues around the circle, with each player moving and making suggestion, as each player can only make 1 suggestion in a room before they must leave it. Once a player feels confident they know the solution, they can make an accusation, which is structured exactly like a suggestion, but, once made, the turn player looks at the cards in the center and if the cards match their accusation, they win the game. Otherwise, they lose, and play continues.

This is a project idea was selected because of how well it illustrates many important principles inherent to artificial intelligence in real world designs. There is a limited amount of information given to the agent, both at the start and throughout the entirety of the game, and as new information is added through correct actions and deductions made by the agent, it uses this new information to better inform its future actions. The information added and deduced is necessary to reason about what actions should be taken next, so it is about to reach its goal of correctly deducing the killer, the murder weapon, and the room the murder occurred in.

While these are all important AI tasks that are well illustrated by the Clue AI, the most important task to the AI, and the problem it illustrates the best, is the problem of knowledge representation. The entirety of the deduction section of the AI can be broken down into a section that first decides how to represent information that is currently know by the AI, and then uses that knowledge to find the necessary solutions to the murder.

All of these aspects of the Clue AI are critical to the creation of AI in general, and the game of Clue is simple enough to illustrate these important concepts without creating an environment that is too complex. This simple environment helps to make this project a perfect balance of representation of complex ideas, while maintaining enough simplicity to be completable by a single person, which also serves to make the AI and its decision-making process very easily explainable and understandable.

Methodology

When building an AI that can play Clue, there are 4 major tasks to must be completed to complete the logic of the game. From least to most difficult, these tasks are: Determine which card to show the turn player if a suggestion is made that they are required to disprove, decide which room to travel to during its turn, form suggestions from the cards it already knows the location of and cards that are unknown, and make deductions from the suggestion it and other players make. The deductions are made in two major

sections: extrapolating information from the suggestion and making inferences from the information extrapolated in the previous section and from previous suggestions. Inferences itself is broken into three sections: inferences from unsolved suggestions, inferences from cards known not to be in players hands, and inferences from the total sets of cards. These will be covered in this order, and in increasing detail as the sections get more complex.

Determining Which Card Should Be Shown

The way the AI determines which card to show is a fairly simple process. The cards that are in the hand of the AI are kept track of in a set, and the way this is done will be explained in more detail along with the process by which deductions are made. When a suggestion is made, it takes the set of cards that are in the AI's hand and compares them to the cards that are in the set that holds the suggestion. It performs an intersection on the two to find the cards that are common between them, and creates a new set ϕ. It then performs another intersection between set ϕ and the set of all people cards, and if there is a card in the resultant set, it means that the person that was suggested is in the AI's hand, and that card is the one shown. If there are no cards left as a result of this intersection, it checks the intersection of ϕ and the set of all weapon cards, and similarly if this doesn't work it checks the intersection of ϕ and all room cards, with the results for both of these intersections being treated exactly the same as with the people set.

This works for 2 reasons: the first is there is only one of each card in the game, so any card can only be in one location and it is not possible for any location to have duplicates. Since this is the case, the AI can maintain all knowledge about card location as sets, which allows for much simpler operation to find cards common or not common between sets. The second is if there are any cards in ϕ then one of those cards is required to be shown. This is shown by the definition of set intersection, as the intersection operator returns all cards that are common between two sets. So, performing an intersection on all the cards in the AI's hand as well as the cards in the suggestion will result in the only cards left being the cards that are common between the two sets, which are the cards in the suggestion that are in the AI's hand.

The final note about this section is why people cards are checked before weapons which are checked before rooms. This is because of the order of importance of the knowledge of each. When a suggestion is made, whichever person is the subject of that suggestion is moved to the room in which the suggestion was made. This can be quite inconvenient, especially if the AI is the person being constantly moved, so showing player cards helps in part to disincentivize this. The weapons are checked second not because of any special property they have, but because of the importance of knowledge of rooms. Because rooms are the only card type that is restricted to a board location, having information about any given room means a player no longer needs to travel to that room, so keeping this information secret as long as possible will help to create the most advantage possible for the AI. These 2 reasons create the importance order of people cards being preferred to be shown most, showing weapon cards is neutral, and showing room cards is the least preferable outcome.

Deciding Which Room to Travel to Next

The AI decides which room to travel to in a similar way to how it determines which card to show. First, if the AI is at the starting location, it goes to the closest room to it. It then checks if a suggestion has been made in the current room.

Before continuing the explanation of the logic of the AI, it is important to explain what the options set it. The AI maintains 3 options sets, a person, room, and weapon option set. The person option set is made up of all the person cards in the AI's hands, as well as the person card that is in the center once this has been deduced. The other sets are maintained similarly for their respective card types. These are maintained because they allow the AI to know which cards are "safe" to use so it does not receive unnecessary information. Ultimately this is a protection for the AI against a smart player who would attempt to show it the same card multiple times. If in a suggestion it uses a person that is in the person option set, no other player can show the AI the person from the suggestion because it is either in its own hand or the center. This restricts the information that can be given to the AI at any given moment and helps to determine other, more important information.

Once the AI checks if a suggestion has been made in the current room, if it determines one has not been made, it determines whether or not to make a suggestion in the current room based on a few different criteria: if the room is in the set of cards whose locations are not yet know and the card in the center is not yet know, or if the room is in the set of room options and the card currently in the center is known. This is done to ensure the AI is always trying to learn new information and, if all important room information has already been learned, it is restricting itself to learning new information about people and weapons.

If neither of these two conditions are met, the AI checks the rooms it has a secret passage to and the neighbors of the current room for those same two criteria. The neighbors and secret passages are maintained in a secret passages and neighbors dictionary that the AI checks for whether each room is unknown, in options, or neither and whether or not the murder room has been deduced. If none of the current room's neighbor's or secret passages meet these criteria, it then selects the closest neighbor it has not recently visited. This is done maintaining a variable that denotes the room

most recently visited before the current room. This is done in order to guarantee that the AI will always be traveling to different locations if none of the neighbors of the current location are able to gain it any new or relevant information.

Forming Suggestions

Suggestion forming is the second most difficult and important task of this AI. In a similar way to the decisions about which rooms to go to next, the decisions about which cards to make suggestions about are dependent on many different criteria, specifically centering on which cards are known and unknown.

Due to the way suggestion work in Clue, the room cannot be changed, so there is no decision from this section about which room to include in the decision, but it is very relevant to making the decision for which cards to include in the suggestion. For this section, learning about rooms are treated with the most importance for the same reasons stated when explaining the AI's decision make for showing rooms last, it is the hardest to gain information about. For the sake of gaining information, people and weapon cards are treated with the same importance, with whichever set currently has less information know about it being given priority over the other.

First, the AI determines which card types are known to be in the center. If the person in the center is known, it will not try to gain new information about people. It operates similarly with regards to learning information about rooms and weapons as well. It then creates two new sets, ϕ_1 and ϕ_2, with ϕ_1 being all currently unknown people and ϕ_2 being all currently unknown weapons. These two sets are used to help determine which person and weapon to include if the person or weapon in the center is still unknown.

The AI then creates a value score for each unknown card. This score is a combination of the number of times it has been used in unsolved suggestion, and the number of players the AI knows do not have the card in their hand. These two lists will be covered more in depth in the next section, but it is important to explain why the AI tracks the cards not in a player's hand.

As an example, assume player two makes the suggestion "Colonel Mustard with the Revolver in the Hall". The suggestion then goes to player three, who can show no cards, and finished with player 4 showing player 2 a card. Then a few rounds later, player 2 again suggests "Colonel Mustard with the Revolver", but this time the suggestion is made in the Dining Room, and player 3 shows player 2 a card, it can be instantly determined which card was shown. Since showing cards is not optional, when player 3 stated they could not show any cards for the initial suggestion, they must not have any cards in their hand from that suggestion. And since there is no way for a player to add cards to their hand once the game has begun, when player 2 later made a second suggestion that they were required to disprove, the only card in that same set that was not already known to not be in player 3's hand was the Dining Room card, meaning that must be the card shown.

The AI also maintains a list of all unsolved suggestion, because it is possible to come back to all previously unsolved suggestions at a later time with new information learned and to be able to solve them now that new card locations have been found.

Going back to the original explanation, the AI creates a value score for each unknown item from the number of times it occurs in each player's set of cards they do not have as well as the number of times it occurs in unsolved suggestions. The higher this value is the more likely it is to provide large amounts of information when solved: the more players know to not have a card, the more likely it is to be in the center, and the more times it is used in an unsolved suggestion, the more likely it is to provide us with other information by being solved.

Once these values have been determined, it selects the person and weapon with the highest of these scores as the baseline for what the suggestion will be. However, if the person is already known, or no person cards had a score, then the person is assigned a random value from person options or from the unknown cards, respectively, and the AI goes through a similar process for the weapons.

Then, if the room is known, the AI returns the suggestion as it is. If the room is not known, since learning rooms should be prioritized, one of the two values will be changed. This is because the AI tries to maintain exactly two unknown values in the suggestion. Since a set of cards not in a player's hand is maintained, it is very beneficial for the AI to have information in these sets. When asking about 3 unknowns, the chances that the player immediately following the turn player will have a card in the suggestion is drastically increased. If said player has a card in the suggestion less information is gained than otherwise possible because it cannot be said definitively if they do or do not have any of the other cards in the suggestion. As a result, the AI limits the potential information that can be returned, but only to a small degree so it can still learn a large breadth of information.

If the room is not known, the person and weapon cards are compared, and whichever card has the highest score is kept or least known information is kept, and the other is set to one of the cards from its respective options list, unless that is impossible in which case the AI will return a suggestion with three unknowns.

Making Deductions: Extrapolating Information

In order to correctly extrapolate data and make deductions, the AI maintains multiple different knowledge bases that it

can reference with all other sections of the program. It maintains sets of all people, weapon, and room cards, as well as lists of all neighbors and secret passages from each room. It also maintains sets of room, people, and weapon options and the previous room it was in. It also maintains a list of all unsolved and solved suggestions, though the list of solved suggestion is mostly used for review and not for any deducing by the AI. It also maintains a set of all cards where the location is known and a set of all cards where the location is unknown, and these sets are updated any time a card location is learned. Finally, it maintains two dictionaries, both of which has key that corresponds to the players in the game and the center of the board, and their data are sets. The first is a dictionary containing the hands of all players in the game and the cards in the center, and any time a card is learned to be in the possession of a player, it is added to the set for their corresponding dictionary entry. The second is dictionary containing the cards known to not be in a player's hand. This was covered in the last section, and will not be covered in-depth here, but it is important to note it only maintains entries for all players other than the AI and not for the center. This is because all cards in the hand of the AI are already known and all cards know to not be in the center must be known to be in a player's hand. The AI also removes cards from these sets as soon as their location is learned because it is not necessary to know where a card is not as soon as it is learned where that card is.

When any suggestion is made, by either a player or the AI, information will be extrapolated. First, if it was a suggestion made by the AI that someone disproved, the AI marks the card shown as being in the hand of the player who showed the card. The suggestion is stored as a set, and any intersection between the suggestion and a card that is already know is removed, to form suggestion μ with removed cards σ. This is done by using the difference operator, which removes all common cards between two sets from one of those sets. Set σ is set equal to the intersection of the initial suggestion with the sets of all players' hands and set μ is set equal to the difference of the initial suggestion and σ. Suggestion μ will now be only relevant unknown information. The dictionary of cards know to not be in a player's hand is now set to be the union of itself and the new set μ for any player that had the opportunity to show a card, as they do not have any cards from this suggestion in their hand but it is only necessary that they do not have the unknown information in their hand.

The last step for this section is to determine if any new information can be learned from μ. This is done by verifying if any cards that were removed from the initial suggestion are cards known to be in the hand of the player who disproved the suggestion. This is a necessary step, because if the player who disproved the suggestion has any cards from the suggestion the AI already knows, it is impossible to determine if the card shown to disprove the suggestion was the card already known by the AI, or some other cards. So, if a card in the suggestion was removed by the hand of the player who disproved the suggestion, there is no more information to be extrapolated. Otherwise, the AI removes from μ the cards know not to be in the hand of the player who disproved the suggestion in the same process as before and creating a new suggestion μ'. This μ' is then added to the list of unsolved suggestion, and the inference step is started.

Making Deductions: Inference from Unsolved Suggestions

The first inference made is whether or not any of the unsolved suggestions can now be solved. It checks each one individually, first removing all information from it again in the same process as before. This is done in order to remove all newly learned information, and, since all information that was already removed cannot be removed a second time, most often when any new information is removed from these suggestions, it will solve it. The suggestion after this information is removed will be called μ''.

If the length of μ'' is now one, and no card that has been removed from μ'' was already known to be in the hand of the player who disproved the suggestion, the only card left in μ'' must be the card they showed. This is a simple truth to prove, as the AI removes cards know to be in all players hands and cards known to be in the center as well as cards know not to be in the hand of the player who disproved the suggestion. Since the player disproved the suggestion, at least one of the cards in the suggestion must be in their hand, and if all cards were removed as stated above, the only possibility for cards left in μ'' is that their location is unknown. And while this is true, if there is only 1 card left in μ'', then, since all cards known to be in locations other than the disproving player's hand were removed, the card left must be the card they showed.

Making Deductions: Inference from Cards Known to Not Be in Player's Hands

There are two important deductions from this section. The first is that if all other players have a card in common that it has been shown they do not have in their hand; it must be in the center. This is true because the AI only tracks cards it does not know the location of. If a card is in a player's don't have set, it cannot be in the AI's hand. With that in mind, there are a limited number of places a card can be, either in the AI's hand, another player's hand, or the center. If all other players share a card they all do not have, it can only be in one of two places, the AI's hand or the center. And if the card is in all other player's don't have sets, this means it cannot be in the AI's hand either, and it must be in the center.

The other deduction is an extension of this style of thinking. In the center can only be one card of each type, one person, one weapon, and one room. If, for example, the person in the center is know there is a new kind of inference that can be made. If all but one of the players share a card in their don't have set that is also a person, but one player does not have that card in their don't have set, that last player must have it. This is for similar reasons to the previous inferences: if it is on the don't have list it cannot be in the AI's hand as it would otherwise have been removed, and since the card is, in this example, a person, it cannot be in the center because the person in the center is already know. Therefore, it must be in the hand of the other players. And if all but one player has been shown to not have said card, it must be in the hand of the player who has not been shown to not have this card.

While this last inference is not as important as the first inference made in this section, it is still important to track, as once it is learned it can potentially lead to previously unsolved suggestions being solvable and providing new information.

Making Deductions: Inferences from the Total Set of Cards

This last inference is the most basic, and the one made by most players when playing Clue. The AI checks if it has learned the person, weapon, and room in the center, and for each one it has not yet learned, it checks to see if it has eliminated all but one possible card, and, if it has, that card is clearly the card in the center. While an important inference to check, this type of inference is ideally never needed as the other inferences would hopefully make the inference for which cards are in the center before all cards themselves have been eliminated. However, this cannot always be the case, and so it is a necessary step to check for.

There is one last important thing to note about the system that makes deductions. As soon as a new piece of information is learned through these deductions, it recursively starts the whole process over again. This is because any information that is learned can immediately be applied to all other pieces of unknown information and can potentially lead to more information being gained.

Evaluation Criteria

This project is to be evaluated on the criteria of whether it is able to correctly deduce the murderer given the same information necessary for a human to make the same deductions. On that bases, it has completely succeeded as it is able to correctly deduce the solution to the murder given correct information and given as many steps as a human would need, if not less steps. However, by the nature of Clue, it cannot guarantee that it will always be the first to reach this deduction. No two players have the same information, and no two players make the same suggestions, so it is possible one the first turn a player makes a suggestion with all three cards in the center than cannot be disproven and wins the game instantly. Because of situations like this, guarantees as to how it will compare to human players will always be impossible to prove and uphold.

Changes

The most significant changes to the project came early on. The initial project was planned to use deep learning and be able to play on its own. Ultimately, it was decided that deep learning was completely unnecessary for a game of the caliber of Clue, as almost identical performance can be attained through shallow learning methods. It is also not able to play the game on its own, it requires a human to feed it the information it requires to play the game. While this is slightly more inconvenient, it allows for it to play the physical board game as well as any other iteration of the game if a person is there to help.

Conclusion

The Clue AI is an AI that can play clue with the same effectiveness of most human players. The deduction section of the program is the most impressive, as it is able to make incredible deductions quickly and efficiently, while still maintaining correctness. In order to improve this project, the areas that need the most improvement are the suggestion creation and board movement areas. While they are currently more than simply functional, they have not been shown to be the optimal solutions as currently implemented, and they would either need to be shown to be optimal, or a new, more optimal method would need to be devised. It could also serve as good practice to implement this system in an environment that would allow it to play clue on its own, but that is an entire project's worth of its own task and will be left for others or for another time.

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