

Comparing question asking strategies for Cluedo

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Abstract The game of Cluedo – also known as Clue – requires working out a ‘murder’ scene by elimination. Beginners typically rely only on cards in their hand and cards they have seen; experts also use propositional logic about cards they have not seen, based on questions asked and answers given.

A game-playing program has been written to test the value of using deductions to guide question-asking. This paper describes how the program has been designed and presents results for five strategies (including a ‘no intelligence’ strategy) for three player games and six player games. The program has been written using JESS (the Java Expert System Shell).

The results were not quite as expected. Using propositional logic did indeed allow the game to be solved in fewer turns, but there were times when adding extra information to the logical deductions made things worse, not better. There is also a strong effect from the mechanics of the game – specifically, which room is chosen as the ‘guilty’ location – on the number of turns required to solve the problem.

It is suggested that strategies might benefit from occasionally breaking away from their highly focussed approach to inject variety into the questioning

The test cases used are listed in an appendix.

1 INTRODUCTION

Winning a game of Cluedo – or ‘Clue’ as it is known in North America – relies on propositional logic. Each player holds some of the twenty-one game cards; in each turn they are allowed to ask for three named cards, and will be shown one of these cards by the next player – or, if the next player has none of the three, by the player after next, and so on. The task is to work out which three cards were put aside at the start of the game and so are not held by any player.

Beginners typically use exhaustive elimination: they keep playing until they have seen (or possess) eighteen of the twenty-one cards that represent possible suspects, murder weapons, or murder locations. Experienced players will also reason about cards they have not seen based on information gathered from questions asked by others.

A game-playing program has been written to test the value of using deductions to guide question-asking. The research hypothesis is that questioning guided by deductions will lead to a solution more quickly than exhaustive elimination; the research question is whether some strategies based on deduced information are more powerful than others in reaching solutions quickly. Three strategies are tested which focus on:

1. Confirming possible deductions;
2. Reducing opponents’ options; or
3. Shrinking the search space.

This paper describes how the program has been designed and presents results for five strategies (including a ‘no intelligence’ strategy) for three player games and six player games. The program is based on the ‘Speed Clue’ variant [2] in which movement between rooms is eliminated – players may enquire about any room at any stage of the game.

The program has been written using JESS (the Java Expert System Shell) [1]. Expert system shells are among the earliest AI programming tools and offer a wide variety of programming approaches, especially if the shell offers and combines rule-based and object-oriented programming, as JESS does.

2 STRATEGIES

The game of Cluedo is played with six ‘suspects’, six ‘weapons’ and nine ‘rooms’. These are recorded on twenty-one cards. At the beginning of the game, one card from each of the three categories is set aside: these represent the murderer, the weapon used and the location of the murder. The remaining cards are dealt out to the players, in equal numbers as far as possible.

On each turn a player can ask the next player if s/he holds any one suspect, any one weapon or any one room card. If that player holds one or more of those cards, s/he must show one of those cards to the first player. If s/he holds none of those cards, they must declare this, and the following player must answer or pass instead.

Players are given a sheet to record their findings. The sheet merely lists the twenty-one cards with a space next to each; it therefore implicitly encourages the belief that all that needs to be recorded is simple information such as whether a card is held by a player, and perhaps who holds it.

The players’ goal is to work out which are the ‘murder’ cards either by exhaustive elimination or by asking for a card which they do not have in their hand and discovering that no-one else possesses it either. The minimum number of turns in which the game can be completed is therefore one turn if someone asks for all three murder cards in their first turn. The probability of such a guess varies between 0.5% and 1% depending on the number of players.

Expert players make use of various sources of information apart from the cards that they are shown on their turn. Such sources include logical information such as:

- Possible cards. If player X asks player Y whether s/he has cards A, B or C and player Y shows a card to player X, then every player can deduce that player Y holds at least one of A, B and C.
- Absent cards. If player X asks player Y for cards D, E and F and player Y passes, then player Y does not have cards D, E or F.
- Full hand known. If player X has seen or deduced every card in player Y’s hand, then player X knows that player Y does not have any of the remaining cards.

It is also possible to use ‘human’ information such as:

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- Assuming that a beginner will always ask for three cards that are not in his hand.
- Assuming that a player who asked for cards A, B and C on turn 1 and D, B and C on turn 2 was shown card A on turn 1.

Finally, expert players will often manage the information that they share:

- If they receive a request for which they have two or more cards, they will prefer to show a card they have already shown to someone else
- If they receive a request for which they have two or more cards, they will prefer to show a suspect or a weapon because rooms are the hardest to deduce.

The system described in this paper uses only the ‘logical’ information listed above. It offers five different strategies:

1. No intelligence: Choose cards to ask for at random, excluding only cards in the player’s hand and cards already seen. (In practice, the order is not random; it depends on the order in which the list of cards is uploaded into the system. This allows the creation of a diverse set of test deals which use cards from the beginning, middle or end of each of the three lists).
2. Deduction only. The system records each player’s knowledge of ‘possible’ cards held by other players, and also of cards that other players do not hold. If there is a set of three ‘possible’ cards and a player knows that two of them belong to somebody else, or are on the ‘not held’ list, for a player, it can deduce that a player must hold the third of those three cards. Its question asking strategy is not to ask for cards in hand, cards seen, or cards deduced.
3. Next-possible: If a ‘possible cards’ list is available for the next player, choose one of those (excluding cards in hand, cards seen, cards not held and cards deduced) along with two other cards to ask about. Preference is given to asking about the room. The goal of this strategy is to confirm the cards held by the next player.
4. Previous-possible: If a ‘possible cards’ list is available for the *previous* player, choose one of those (excluding cards in hand, cards seen, cards not held and cards deduced) along with two other cards. Preference is given to asking about the room. The goal of this strategy is to reduce the options for opponents to hide cards; since all but one are likely not to have the ‘possible card’, they will find it more difficult to conceal either of the other two requested cards.
5. Next-not-held. If some cards are known to be absent from the next player’s hand, ask about one or two of these (with the same exclusions as for strategies 2-4). The preferred strategy is to choose two cards not held by the next player, along with one card not held by the player after next; failing that, the system chooses two cards not held by the next player and one other; failing that, it chooses one card not held by the next player and two others. The goal is to search for a possible solution by finding cards that no other players hold; asking about cards that some players are known not to hold shrinks the search space.

For strategies 2-5, if there are no cards that fit into the strategy’s rules, the fallback is to use the ‘no intelligence’ strategy.

3 RESULTS

The strategies were run on six different test ‘deals’ between three players and the same ‘deals’ split in half for six players. Every player used the same strategy in any one game. The full ‘test deals’ (for 3 player games) are listed in Appendix 1 in case anyone wants to repeat the experiments described in this paper. Then, for completeness, a generator was used to run the strategies on every possible deal (or to be precise, on every possible combination of ‘guilty’ cards, swapping cards in and out of existing hands as needed).

The test deals were designed to vary the position in the list of cards of the ‘murder’ cards. The ‘murder cards’ for the six deals were:

1. Professor Plum, Lead Pipe, Hall. Plum is the 6th and final person in the list of suspects; Lead Pipe is listed fourth in the list of six weapons; Hall is listed as the first of the nine rooms. This will be represented as [6, 4, 1].
2. Professor Plum, Spanner, Kitchen [6, 6, 9]
3. Mrs White, Rope, Ballroom [3, 3, 5]
4. Miss Scarlett, Rope, Kitchen [1, 3, 9]
5. Mrs Peacock, Spanner, Dining Room [2, 6, 2]
6. Miss Scarlett, Revolver, Hall [1, 1, 1]

Because JESS tends to work sequentially down a list when pattern matching, the following predictions can be made:

- Deal 2 will take the longest to solve
- Deal 6 should be solvable in 1 turn
- The other four deals should take approximately the same time to solve, with deal 5 perhaps marginally the fastest and deal 4 marginally the slowest.

Predictions can also be made about the strategies:

- Since the ‘intelligent’ strategies fall back to the No-Intelligence strategy when they have no legal move, it is very unlikely they will do any worse than the No-Intelligence strategy
- The Deduction strategy should perform the least well of the four ‘intelligent’ strategies since it uses the least information.
- The other strategies should have a bigger advantage over the first two strategies in longer games, since more and more information becomes available as games go on.

The total number of rounds required to find a solution is shown in Table 1, excluding Deal 6 which was always solved in 1 turn as predicted.

	Deal 1	Deal 2	Deal 3	Deal 4	Deal 5	All
3 players:						
No intelligence	6	12	6	7	4	6.88
Deductions	6	12	6	7	4	6.07
Next-possible	6	13	5	11	3	6.55
Previous-possible	3	11	5	7	4	5.80
Next-not-held	5	13	4	6	4	5.25
6 players:						
No intelligence	7	16	7	9	5	8.33
Deduction	7	16	7	9	5	8.27
Next-possible	6	4	9	10	4	6.62
Previous-possible	10	6	8	13	6	8.35
Next-not-held	3	8	5	8	5	6.69

Table 1. Number of turns for any player to reach a solution

The results are not exactly as predicted. Some comments regarding the predictions:

- Deal 2 took the longest to solve for the less intelligent strategies, partially fulfilling the prediction.
- Deal 5 was the fastest to solve of the other deals and deal 4 the slowest, but the differences cannot be described as marginal.

Regarding the strategies:

- The deduction strategy performed hardly any better than the no-intelligence strategy. This was despite the fact that an average of 15 deductions per player had been made by the end of Deal 2 in the 6 player game.
- The Next-Not-Held strategy seems to be the best strategy overall, and the most consistent of the intelligent strategies.
- The two strategies that focus on possible cards that other players might hold showed very variable performance, sometimes being the best strategy by far, and on other occasions performing worse than the no-intelligence strategy. Next-Possible seems to be the better of the two.

It appears that focussing on cards that other players may hold is a lottery; sometimes it leads to excellent performance, at other times it leads a player to waste turns on a red herring. It may well depend on whether the random choice picks a card that the next player actually holds; choosing one the player does not hold seems to lead to better performance. Consider the following trace for deal 5, 6 players, Next-Possible strategy:

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jess> (run)
Which game do you want to play? [1-6]
-> 5
Which strategy do you want to play? [ni,d,np,pp,nh]
-> np
player1's turn:
player2, do you have any of: prof-plum, candlestick or study?
player2 has study
player2's turn:
player3, do you have any of: miss-scarlett, dagger or hall?
player4, do you have any of: miss-scarlett, dagger or hall?
player4 has hall
player3's turn:
player4, do you have any of: miss-scarlett, revolver or dining-room?
player5, do you have any of: miss-scarlett, revolver or dining-room?
player6, do you have any of: miss-scarlett, revolver or dining-room?
player1, do you have any of: miss-scarlett, revolver or dining-room?
player1 has miss-scarlett
player4's turn:
player5, do you have any of: prof-plum, spanner or kitchen?
player5 has prof-plum
player5's turn:
player6, do you have any of: col-mustard, spanner or study?
player1, do you have any of: col-mustard, spanner or study?
player1 has col-mustard
player6's turn:
player1, do you have any of: col-mustard, rope or hall?
player1 has col-mustard

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Figure 1: 6-D5-NP trace, part1

By the time player6's turn comes up, he knows that player 1 has one of Miss Scarlett, the Dagger or the Hall; and one of Colonel Mustard, the Spanner or the Study. Two of these six cards are actually 'murder cards' (in this deal, Mrs Peacock did it with the spanner in the dining room) but player6 decides to focus on Colonel Mustard, and is 'rewarded' by having player1 show him that card.

The same thing happened on the second round – player6 focussed on Miss Scarlett and was shown that card by player1. By the third round of the same game (Figure 2), with no further 'possible' information available, player6 has switched to focussing on the Spanner, but his query is answered by player4 who has the Hall. On the fourth turn, player6 focusses on the Dining Room and adds it to his previously unanswered Person and Weapon queries, and arrives at the right answer.

Some interim conclusions that can be drawn are:

- Using propositional logic about present and absent cards to guide questioning does improve performance.

- Deducing the correct room is the hardest task, so it is a good idea to focus questions on finding the room.
- Asking for cards that are known to be absent from the next player's hand (focussing on a possible solution) is usually a better approach than asking for cards that might be in that hand (focussing on information collection).
- There are times when logical deduction makes performance worse than using no intelligence at all.

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player6's turn:
player1, do you have any of: mrs-peacock, spanner or hall?
player2, do you have any of: mrs-peacock, spanner or hall?
player3, do you have any of: mrs-peacock, spanner or hall?
player4, do you have any of: mrs-peacock, spanner or hall?
player4 has hall
player1's turn:
player2, do you have any of: mrs-peacock, revolver or dining-room?
player2 has revolver
player2's turn:
player3, do you have any of: col-mustard, spanner or billiard-room?
player4, do you have any of: col-mustard, spanner or billiard-room?
player5, do you have any of: col-mustard, spanner or billiard-room?
player6, do you have any of: col-mustard, spanner or billiard-room?
player6 has billiard-room
player3's turn:
player4, do you have any of: mrs-peacock, dagger or hall?
player4 has hall
player4's turn:
player5, do you have any of: col-mustard, revolver or lounge?
player6, do you have any of: col-mustard, revolver or lounge?
player1, do you have any of: col-mustard, revolver or lounge?
player1 has col-mustard
player5's turn:
player6, do you have any of: mrs-peacock, spanner or hall?
player1, do you have any of: mrs-peacock, spanner or hall?
player2, do you have any of: mrs-peacock, spanner or hall?
player3, do you have any of: mrs-peacock, spanner or hall?
player4, do you have any of: mrs-peacock, spanner or hall?
player4 has hall
player6's turn:
player1, do you have any of: mrs-peacock, spanner or dining-room?
player2, do you have any of: mrs-peacock, spanner or dining-room?
player3, do you have any of: mrs-peacock, spanner or dining-room?
player4, do you have any of: mrs-peacock, spanner or dining-room?
player5, do you have any of: mrs-peacock, spanner or dining-room?
player6 says the guilty party is mrs-peacock with spanner in dining-room!

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Figure 2: 6-D5-NP trace, part2

4 RELATED WORK

There have been more than one Clue/Cluedo competition where human players write their own artificially intelligent agent that competes against other agents. Hansen et al. [3] developed the Glomus server to help teach undergraduates Prolog; [4] ran a competition that simulated over 25,000 games between different agents. However, neither of these references say much about the strategies used, although [3] describes how smarter students used 'human' information about the less intelligent agents written by their fellow students!

There is also a Cluedo agent written in Prolog freely downloadable from GitHub [5]. However, the only 'intelligence' it has is in deducing what cards other players hold; it does not appear to have any question-asking strategies.

A free software Cluedo game written in C# can be downloaded from [6]. It attempts to simulate the board game closely but its note-taking pad is different; it allows marking of players who are known to have cards, and of players who are known not to have cards. There is no method provided for marking possible cards that a player may hold, nor for recording other information such as which AI players have been shown which cards from the human's hand.

5 FUTURE WORK

There are multiple possible avenues for future work:

- Create a strategy that combines reasoning about 'possible' cards and 'not held' cards.
- Test the strategies against each other (have different players use different strategies in a single game).

- Extend the ‘intelligent’ strategies to deal with information about all other players, not just the next or previous player.
- Add probabilistic inference. If a player is asked for cards P1, W1 and R1 and shows a card, then is later asked for P2, W1 and R2 and shows a card again, it seems intuitive to assume that there is a higher probability that the player has W1 than any of the other pairs of cards. How much higher? If the player is asked for W1 a third time, how does that affect the probability?
- Introduce deductions based on ‘human’ information. This may well be the most powerful extension to the program to make it a stronger Cluedo player. The reasons are:
 - o Correctly guessing an opponent’s strategy provides a significant extra information source; it is now possible to reason about why they chose the cards they asked about as well as about the cards they showed to other players.
 - o Any strategy based on probabilistic inference (see above) must take opponents’ strategies into account, because there are some strategies in which an opponent will avoid showing certain cards. A statistical approach based on belief and uncertainty modelling that does not take such strategies information into account is unlikely to perform well.
 - o It opens the possibility for using Monte Carlo simulation to hypothecate various strategies that the other players might be following and to choose the best questions to ask accordingly.
- Introduce strategies that include asking for cards that are already present in a player’s hand. This is sometimes done in the board game for misdirection but may also be done in an attempt to confirm whether one unknown card is held by any player.
- Switch from Speed Clue to Cluedo and introduce planning algorithms to move from room to room efficiently.
- Modify those planning algorithms to move other players to a player’s current location during a turn (this is part of the requesting process in the board game) not for the sake of logical deduction but to keep that player away from another location.

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APPENDIX

This appendix shows the full contents of each deal in the 3-player version of the game. The 6-player version split each player’s holding in half, assigning half of player1’s holding to player4 and so on.

Master lists of cards:

Suspects: miss-scarlett mrs-peacock mrs-white col-mustard rev-green prof-plum

Weapons: revolver dagger rope lead-pipe candlestick spanner

Rooms: hall dining-room lounge billiard-room ballroom library study conservatory kitchen

Test deals for 3 player game:

Deal 1: (guilty game1 prof-plum lead-pipe hall)

(cards game1 player1 miss-scarlett col-mustard rope spanner ballroom library)

(cards game1 player2 mrs-peacock rev-green dining-room lounge study revolver)

(cards game1 player3 mrs-white dagger candlestick billiard-room conservatory kitchen)

Deal 2: (guilty game2 prof-plum spanner kitchen)

(cards game2 player1 miss-scarlett study library rope lead-pipe rev-green)

(cards game2 player2 lounge hall revolver mrs-peacock ballroom dining-room)

(cards game2 player3 col-mustard dagger billiard-room mrs-white conservatory candlestick)

Deal 3: (guilty game3 mrs-white rope ballroom)

(cards game3 player1 rev-green col-mustard revolver lead-pipe hall library)

(cards game3 player2 mrs-peacock prof-plum dining-room lounge study spanner)

(cards game3 player3 miss-scarlett dagger candlestick billiard-room conservatory kitchen)

Deal 4: (guilty game4 miss-scarlett rope kitchen)

(cards game4 player1 rev-green col-mustard revolver lead-pipe hall library)

(cards game4 player2 mrs-peacock prof-plum dining-room lounge study spanner)

(cards game4 player3 mrs-white dagger candlestick billiard-room conservatory ballroom)

Deal 5: (guilty game5 mrs-peacock spanner dining-room)

(cards game5 player1 miss-scarlett col-mustard rope lead-pipe hall library)

(cards game5 player2 rev-green prof-plum kitchen lounge study revolver)

(cards game5 player3 mrs-white dagger candlestick billiard-room conservatory ballroom)

Deal 6: (guilty game6 miss-scarlett revolver hall)

(cards game6 player1 rev-green col-mustard rope lead-pipe ballroom library)

(cards game6 player2 mrs-peacock prof-plum dining-room lounge study spanner)

(cards game6 player3 mrs-white dagger candlestick billiard-room conservatory kitchen)