Cooperative Partner Agent of Seven-Card-Stud Poker

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Abstract— *This paper aims at the construction of a cooperative partner agent that plays a seven-card stud poker game with a human partner against an opponent player. If a human player needs some advice on a game, the partner agent gives a human partner player strategy for a game and its grounds. A human player can also ask some questions about the current situation of a game. If a human player tries to take different strategy from the one presented by the partner agent, the partner agent calls human player's attention to the presented strategy with its grounds. Fuzzy theory and case based reasoning are applied to decision-making part in the partner agent. This paper also performs subject experiments to evaluate the effectiveness of the presented partner agent, where each subject plays games with/without the partner agent.*

Keywords— game with imperfect information, poker game, cooperation, fuzzy inferences, case based reasoning

1 Introduction

In our daily life we are often confronted with decision-making problems under uncertain situations. Although we think of many alternatives or various different opinions under such situation [1], it is usually difficult to solve them completely. Therefore, we often get other perspectives or hints to solve problems by exchanging opinions among others or by taking advice from others. An adviser with ripe experience may give better advice on decision-making problems. Exchanging opinions or taking advice may lead to some solution that cannot be found by oneself or to some other understanding on problems. From this point of view, there are many studies on decision support systems [2,3,4,5,6]. However, these systems only support users' decision and do not consider decision-making program from the viewpoint of cooperation with human users.

This paper considers the situation in which human makes decision in cooperation with a computer. In this paper, as an example of decision-making problem, seven-card-stud poker game, a kind of a game with imperfect information [7], is taken because situations estimate is usually difficult under uncertainty of poker game situations. Although there are also some studies about negotiation agent in a game, e.g., a MONOPOLY game [8], or poker playing systems [9,10,11], studies on decision-making from the viewpoint of cooperation with human players in a game are not found.

This paper aims at the construction of not a mere poker playing system but a partner agent, which has a discussion with a human player on game strategy in a seven-card-stud poker game cooperating with a partner player. The presented agent is based on the authors' previous seven-card-stud poker game playing system [12,13,14], and is enlarged from our previous partner agent [15] in a sense that the system gives some advice to a human partner player using case based reasoning. A human player plays poker games with the presented partner agent that cooperates with a human player by not only presenting information on game situations but also performing question and answering of game strategy. Therefore, this paper considers not only gain/loss of point but also the human partner player's evaluation of usefulness/helpfulness.

The organization of the paper is as follows. In Section 2 a seven-card-stud poker game used in this paper is explained. Section 3 presents the partner agent consisting of the decision-making module and the cooperation module. Section 4 mentions subject experiments performed in order to show the usefulness of the presented partner agent and their results. Final section shows conclusions of this paper.

2 Seven-Card-Stud Poker

2.1 Stud Poker

A stud poker game is different from a draw poker one. And although a stud poker game has various kinds of game variations, face-down and face-up cards are dealt to each player in every stud poker game. The card dealt face down is called a hole card that only a card owner can see. On the other hand the card dealt face up is called an up card that all players can see.

2.2 Seven-Card-Stud Poker

This paper considers the situation in which a human player and the partner agent play a poker game together against the previous poker playing system [13,14] as an opponent player. This section describes rules of a seven-card-stud poker game used in this paper.

After both players (a human player and the playing system) pay 5 points as the ante, two hole cards and one up card are dealt to each player, and the first betting round is started. The second player must bet at least the same amount of bet as the first player's one, where one player can raise the betting point only once at each betting round, and the upper limit of betting points is assumed to be total points betted so far. When both players' betting points become even, a next card is dealt to each player and the next betting round is started. The fourth, the fifth and the sixth cards are face-up cards, and the seventh

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card is a hole card. After all cards are dealt to and betting rounds are ended, each player makes a decision which hole card is revealed. Each player reveals one hole card and the betting round is started. If any players still don't fold a game, the procedure of revealing hole cards and that of betting round are continued. Bluff strategy or slow play is also often taken in the procedure of revealing hole cards. If both players continue a game after the final betting round, they show their final hole cards each other, which is called Showdown, and the player having a stronger poker hand with five cards out of seven is a winner of a game.

2.3 Poker Hands

This paper considers 10 sorts of poker hands including no pair (high card). Scores of these hands are defined as shown in Table 1. In this paper, scores are simply defined as 10 scales from 0 to 9 because the linear scale is simple.

Table 1:Score of poker hands

Poker Hands	Scores	Poker Hands	Scores
Nothing	0	Flush	5
One Pair	1	Full House	6
Two Pairs	2	Four of a Kind	7
Three of a Kind	3	Straight Flush	8
Straight	4	Royal Straight Flush	9

3 Partner Agent

3.1 Relationship between Agent and Players

A human player plays a poker game in cooperation with the partner agent against an opponent player. It is assumed that when the partner agent is called by a human player according to game situations, the agent presents its strategy to a human player. Furthermore, when a human player has some questions on some strategy, the partner agent answers these questions. It is also assumed that the partner agent has same information as the one a human player does. Fig.1 shows the decision-making procedure of the partner agent, which has the decision-making module and the cooperation module.

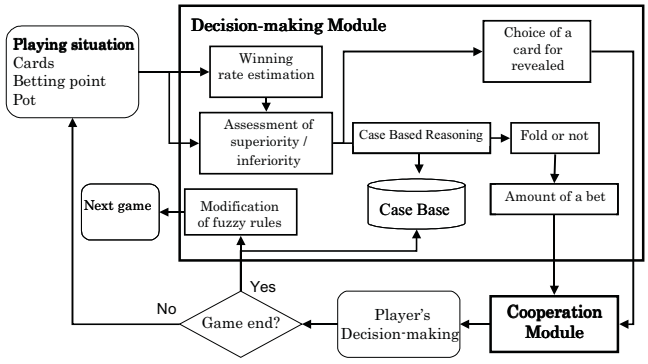

Figure 1: Decision-making procedure of partner agent

3.2 Decision-making Module

The decision-making module of the partner agent consists of six parts, winning rate estimation, assessment of superiority/inferiority, decision-making to fold or not, decision-making on betting points, choice of a card to be revealed and modification of fuzzy rules.

3.2.1 Winning Rate Estimation

In order to estimate the winning rate of a partner player, the agent suppositionally assigns possible combination of cards to human and opponent players' hole cards and to their up cards dealt from now on. The agent makes a judgment on human partner player's winning or losing. The agent repeats this trial and counts the number of the partner player's winning. Let this repeating trial times and the number of human partner player's winning be N_{times} and N_{win}, respectively. The winning rate is defined by

$$P_{win} = \frac{N_{win}}{N_{times}} \cdot \tag{1}$$

In this paper, N_{times} is fixed to be 10000.

3.2.2 Assessment of Superiority/Inferiority

The relative strength of the human partner player's poker hand to the opponent player's one is defined by

$$expect = 2(P_{win} - 0.5) . \tag{2}$$

The *expect* means that the larger the *expect* is, the higher the possibility of the superiority of a human player's hand is. In this paper the obtained *expect* is adjusted by fuzzy inference using fuzzy rules considering the tendency of opponent player's strategy, betting points and the number of turn. Table 2 shows an example of fuzzy rules at the early game stage, where the turn is normalized by 7, which is the maximum number of betting round times in a seven-card-stud poker game, and betting points are normalized by the pot. As Table 2 shows, the fuzzy rules have parameter values $t_{ij} \in [0,100]$ called the tendency values. The tendency value means that if t_{ij} is larger than 50, an opponent player tends to take aggressive strategy, and if t_{ij} is smaller than 50, an opponent player tends to take passive strategy [14]. The initial values of all tendency values are defined to be 50 and the tendency values are changed every game according to the opponent player's strategy.

Table 2: Fuzzy rules for assessment of superiority/inferiority at early game

Adjustment degree (Turn is Early)		Opponent's bet		
		Few	Middle	Much
Hand strength	Weak	Negative t_{11} Positive	Negative t_{12} Positive	Negative t_{13} Positive
	Strong	Negative t_{21} Positive	Negative t_{22} Positive	Negative t_{23} Positive

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The fuzzy inference using these fuzzy rules is performed as follows. Let the result of fuzzy inference using the Positive consequent part and that using the Negative consequent part be $C_{positive}$ and $C_{negative}$, respectively, where the min-max inference method and the center of gravity are used in the fuzzy inference [18].

$$infer = C_{positive} \times (\frac{t_{ij}}{100}) + C_{negative} \times (1 - \frac{t_{ij}}{100}) . \quad (3)$$

And $expect$ is adjusted in the range of [0,1] using the result of the fuzzy inference (3) by

$$result = \begin{cases} expect + (1 - expect) \times infer \\ \qquad (0 \le infer \le 1) \\ expect + (expect + 1) \times infer \\ \qquad (-1 \le infer \le 0) \end{cases} . \quad (4)$$

The $result$ is the assessment result of the superiority/ inferiority of a human player's poker hand.

3.2.3 Case Based Reasoning

In order to use case examples in past games for decision-making, case based reasoning (CBR) [17] is applied in this paper. The following items are considered as indices of problem features used in CBR: (i) $result$ in Eq. (4), (ii) opponent's bet, (iii) change of $result$ which is the difference between $result$ of the current situation and $result$ of the previous situation, (iv) change of opponent's bet which is the difference between opponent's bet of the current situation and opponent's bet of the previous situation, (v) $potential$ in Eq. (7), (vi) change of potential which is the difference between $potential$ of the current situation and potential of the previous situation, (vii) the number of turn.

The following items are considered as solutions of a problem: (i) a player folds a game or not, (ii) strategy is successful or not. The similarity degree of each item is obtained by

$$Sim_i = 1 - |Past_i - Current_i| , \quad (5)$$

where $Past_i (i = 1,2,...,n)$ is index of the i-th problem feature in a past case, $Current_i (i = 1,2,...,n)$ is the index of the i-th problem feature in a current case, and n is the number of problem features. In this paper, n is fixed at 7. The whole similarity degree is obtained by

$$Sim_{whole} = \frac{\sum_{i=1}^{n} Sim_i}{n} . \quad (6)$$

Case with the largest whole similarity degree larger than 0.9 is defined as the most similar case.

3.2.4 Decision to Fold or Not

From the first through the fifth turns the partner agent has the following decision procedures. When the agent assesses the partner player's hand at superiority and continuing a game is chosen as strategy by CBR, then the partner agent advises to continue a game. However, when folding a game is chosen as strategy by CBR and the whole similarity degree is larger than 0.95, then the partner agent advises to fold a game even if the agent assesses the hand at superiority. When the partner agent assesses the partner player's hand at inferiority, the partner agent makes a decision by the fuzzy inference whether a partner player should fold a game or not. An example of the rules is; if opponent's betting points are large and the number of turn is large, then fold a game with high possibility. If the fuzzy inference result($\in [0,1]$), i.e., the possibility of folding a game, is larger than a uniformly random generated number($\in [0,1]$), the partner agent makes a decision to fold a game. However, when continuing a game is chosen as strategy by CBR and the whole similarity degree is larger than 0.95, then the partner agent advises to continue a game even if the agent assess the partner's hand at inferiority.

In the sixth and the seventh turns, a poker hand is already determined because the seventh card is dealt. However, even if the hand strength is assessed at inferiority, there is sometimes a case where it is possible to take bluff strategy. The presented agent decides whether bluff strategy should be taken or not according to the following procedures.

In order to choose a hole card to be revealed, the potentiality is obtained by the following way. Assuming that one partner player's hole card is revealed, possible combinations of cards are assigned to remaining hole card(s). The expected value of the strength of possible poker hands is obtained by

$$potential = \sum_{i=1}^{m} u_i p(u_i) , \quad (7)$$

where m is the number of partner's possible poker hands, u_i is the score of the possible hand as shown in Table 1, and $p(u_i)$ is the probability of u_i. This expected value is called $potential$ in this paper. In the same way, the agent obtains the expected value of opponent player's hand called $Opp\_potential$. If Eq. (8) holds good, the partner agent decides not to fold and to take a bluff strategy, when Eq. (8) is considered by previous work [15]. However, even if the partner agent decides not to fold, when folding a game is chosen as strategy by CBR and the whole similarity degree is larger than 0.95, then the partner agent advises to fold a game.

$$potential \ge Opp\_potential + 1.3 \quad (8)$$

3.2.5 Decision on Betting Points

Let the upper limit and the lower limit of betting points be $upper$ and $lower$, respectively, where these limits are dependent on the betting round and are provided by the poker game rules. In this paper the upper limit is assumed to be the total points betted so far and the lower limit is assumed to be 5 points. The bet points are obtained by

$$C_{bet} = lower + a(upper - lower) , \quad (9)$$

where a is defined by

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$$a = \frac{result + 1}{2} + noise\,, \tag{10}$$

where $noise$ is a normally distributed random number with the mean value 0 and the variance 0.1. If bluff strategy is considered by the agent, C_{bet} in Eq. (9) is obtained using a defined by

$$a = \frac{(potential/9) + 1}{2}, \tag{11}$$

where $potential$ is obtained by Eq.(7) and is normalized by 9, i.e., the maximum score of poker hands defined by Table 1. This means that the agent bets large points in order to make the partner player's hand look strong using bluff strategy.

3.2.6 Choice of a Card to be Revealed

In the fifth and the sixth turns, after the betting round is finished, each player chooses one hole card to be revealed and turns it face up. When the agent assesses a partner's hand at superiority and the hand is already shown in face-up cards, a card to be revealed is chosen at random. When the agent assesses a partner's hand at superiority and the hand is hidden in hole cards, the agent advises to reveal the card at the rate of 80%, of which *potential* is the lowest. The agent advises to reveal the card at the rate of 20%, of which *potential* is the second lowest. When the agent assesses a partner's hand at inferiority, the agent advises to reveal the card of which *potential* is the highest.

3.2.7 Modification of Fuzzy Rules

All cards are shown at the game end and both players' hands are revealed. Every one game the modification part of fuzzy rules estimates the change of the tendency value considering the difference between the estimated relative hand strength and actual hand strength by using fuzzy inference. The modification is performed for the fuzzy rule of which satisfaction degree is the highest in the assessment of superiority/inferiority. The fuzzy rules for modifying the fuzzy rules for assessment of superiority/inferiority have the following form of statement. (1) If the estimated relative poker hand strength is lower than the actual poker hand strength, then the tendency value is changed to be small. (2) If the estimated relative poker hand strength is higher than the actual poker hand strength, then the tendency value is changed to be large. (3) If the estimated relative poker hand strength and the actual one are even, then the tendency value is not changed.

The tendency value is actually changed considering the last five estimated changing values of the tendency value and the latest changing value in order to consider opponent player's tendency in a long period.

3.3 Cooperation Module

The cooperation section has two parts. One part gives a human partner player strategy to take in the current game situation and its grounds. The other gives a human player reply to human player's questions about the current game situation.

3.3.1 Strategy Presentation

Agent's strategy presentation to a human partner player is performed at the decision-making process in each betting round or at the process of the human player's choice of a hole card to be revealed after the fifth turn. When the partner agent is called by a human player, the agent gives strategy for the current game situation.

3.3.1.1 Decision to fold or not to fold

At the beginning of each betting round, when a human player calls the partner agent, the partner agent presents its decision and its grounds to a human player according to the assessment of superiority/inferiority obtained by Eq. (4). If the agent decides to fold according to 3.2.4, then the agent presents its grounds to a human player. And when there are case examples similar to the current situation in a game, the partner agent presents a CBR result to a human player. For example, the partner agent says that you have past similar case examples, you folded games in the past similar situations, and that folding a game is good solution for the current situation.

3.3.1.2 Decision of amount of bed

The partner agent presents the point value obtained by 3.2.5. For example, when the agent decides the betting point to be 10, the agent says that 10 points should be bet for the current situation.

3.3.1.3 Decision to call

After an opponent player bets some points, these decision procedures are performed. The agent decides to fold or not as the same procedures in 3.4.1.1

3.3.1.4 Choice of a card to be revealed

The agent presents a card chosen by the procedure in 3.2.6

3.3.1.5 A human player takes another strategy

Although the agent presents strategy to fold a game to a human player, if a human player tries to take different strategy from the presented one, the agent calls the attention to a human player about the game continuation. For example, the agent presents *you should fold this game, because your hand is weak and opponent player's bet is large*.

3.3.2 Answer to Player's Question

When a human partner player asks the agent some question about the current game situation, the agent replies to it.

Table 3: Linguistic expressions corresponding to t_{ij}

t_{ij}	Linguistic Expressions
100-70	Very aggressive
70-60	Aggressive
60-50	Rather aggressive
50-40	Rather passive
40-30	Passive
30-0	Very passive

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3.3.2.1 Human player's game playing tendency

When the agent gets a question about human player's game playing tendency, the agent presents linguistic expressions based on the tendency value t_{ij} explained in 3.2.2. Although the tendency value t_{ij} is essentially obtained for an opponent player, the partner agent can obtain not only an opponent player's tendency value but also a partner player's one by the same procedures described in 3.2.7. For example, the agent says that a human partner player tends to be passive in the game situation such as the current one. Table 3 shows the linguistic expressions corresponding to t_{ij} .

3.3.2.2 Estimated expected opponent player's hand

The agent performs simulation repeatedly by assigning possible combination of cards to opponent player's hole cards and/or opponent player's cards dealt from now on. Then, the agent estimates the opponent player's poker hand with the highest hand probability and the poker hand with its probability. The agent presents these poker hands and their estimated probabilities to a human partner player. For example, the agent says that the opponent player's hand with the highest probability is One Pair with 46.9% and that the estimated highest score hand is Straight with 10.5%. If a human partner player asks the agent about other poker hands, the agent also replies them.

3.3.2.3 Estimated expected human player's hand

The agent performs simulation repeatedly by assigning possible combination of cards to a human partner player's cards to be dealt from now on, and obtains the partner player's poker hand with the highest hand probability and the highest score poker hand with its probability. Then, the agent presents these poker hands and their estimated probabilities to a partner player. If a human partner player asks the agent about other poker hands, the agent also replies them.

3.3.2.4 Estimated human player's hand strength from opponent player's side

The agent performs simulation repeatedly by assigning possible combination of cards to a human partner player's hole cards and cards to be dealt from now on, and obtains the partner player's poker hand with the highest hand probability and the highest score poker hand with its probability. Then the agent presents these poker hands and their estimated probabilities to a partner player. These probabilities give much information for decision making to a human player whether bluff strategy can be taken or not. If a human partner player asks the agent about other poker hands, the agent also replies them.

4 Experiments

4.1 Experimental Procedures

Subject experiments are carried out in order to evaluate the effectiveness of the presented agent. Each subject plays 30 poker games with the presented partner agent against the poker playing system that has the winning rate estimation part added to our previous playing system, and other 30 poker games without the partner agent. If all 30 games are finished by a showdown, prepared cards are set to have 15 wins and 15 loses, respectively. Subjects are divided into two groups in order to analyze playing strategy in every game with/without the partner agent. Cards in each card set are dealt to all subjects in the same order. That is, all subjects play games on the same condition in the experiments. However, subjects do not know it.

The number of subjects is 12. Although they are novices of a poker game, they have knowledge on poker game rules.

4.2 Experimental Results

4.2.1 Gain/Loss of subjects

Table 4 shows the overall gain/loss points of each subject with/without the partner agent against the playing system. Wilcoxon signed-rank tests [18] of gain/loss points of all subjects with/without the partner agent are carried out. The observed value is 0.98, and significance level 5% is 1.65 on directional test. The null hypotheses are not rejected. This test result shows that there is no difference between gain/loss points with the partner agent and those without the partner agent. However, it is found that nine subjects out of twelve can get more points with the partner agent than without it. Subjects B and H bet large point in betting rounds because both subject and partner agent assess their poker hand at superiority. Therefore, they lose a lot of points. For example, although player hand is tree of a kind, however, opponent player hand is straight, and player and partner agent assess their poker hand at superiority. It is the reason why there is no difference between gain/loss points with the partner agent and those without the partner agent.

Table 4: Gain/Loss of subjects

Subject	without partner agent	with partner agent
A	-17925	2313
B	18217	-79140
C	8193	13817
D	14789	110104
E	12015	-12367
F	-225734	-87563
G	13817	87509
H	-293177	-400371
I	21123	52980
J	19055	21763
K	-52172	-16293
L	-121285	-31182

4.2.2 Evaluations of partner agent

4.2.2.1 Usefulness of partner agent

After the experiments, subjects evaluate the usefulness of the partner agent with a 5-points grade, 5: very useful, 4: useful, 3: neutral, 2: useless, 1: very useless. Fig. 2 shows the evaluation results. Ten subjects out of twelve mark 4 or 5 and the average score among all subjects is 4.2, i.e., useful. And there are no subjects marking 2 or 1. Then subjects' evaluation of the partner agent is high. As a mater of fact, some subjects have comments that the partner agent is useful for the estimation of

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opponent player's hand and the estimation of superior/inferior of the partner player's hand. And other subjects have comments that decision of betting points becomes easier with the partner agent than without agent because decision of betting points by himself is very difficult for him.

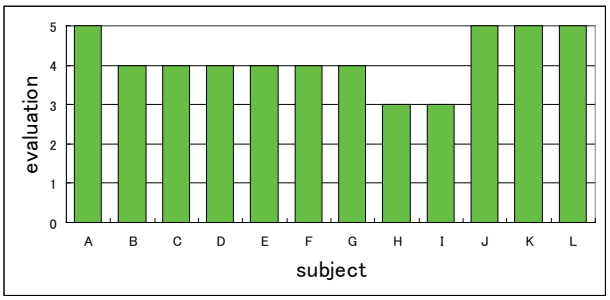

Figure 2: Usefulness of partner agent

4.2.2.2 Learning effect of partner agent

In order to confirm the learning effect of the presented partner agent, after the experiments, the subjects also evaluate whether the partner agent's advices are helpful or not with a 5-points grade, 5: very helpful, 4: helpful, 3: neutral, 2: unhelpful, 1: very unhelpful. Fig. 3 shows the evaluation results. Seven subjects out of twelve mark 4 or 5 and the average score among all subjects is 3.6, i.e., more or less helpful. And there are no subjects marking 1. In this paper, the learning effect is simply evaluated by subjective assessment and subjects' comments analyze the learning effect objectively. Some subjects have comments that they feel that the partner agent's advises are helpful because the partner agent gives them advices referring to case examples them advices are intelligible to them. It is found that the agent gives partner players good advices using CBR. However, some subjects negative comment. Subject H evaluates the partner agent's advices are not helpful because although he wants to play a game more aggressively, the partner agent advises him to fold a game referring to case examples.

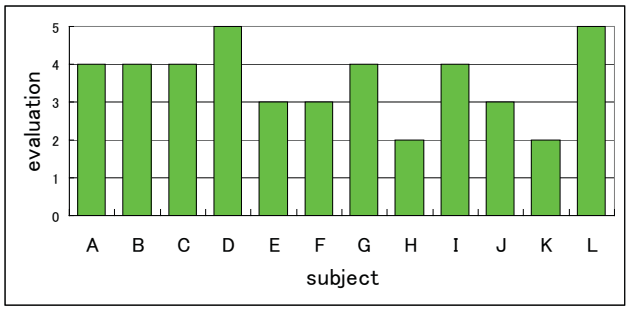

Figure 3: Helpfulness of partner agent's advices

5 Conclusions

This paper constructs a partner agent that supports a human player in playing a seven-card stud poker game. This agent presents its own strategy and/or replies some questions about game strategy in the current game situation when a human player calls it. In order to make use case examples in past games, CBR is also applied. Subject experiments are performed to evaluate the effectiveness of the presented partner agent. Experimental results show that although subjects do not necessarily get more points with the partner agent than without the agent from the viewpoints of gain/loss points, subject's evaluation of usefulness of the partner agent is high. And the evaluation of helpfulness of partner agent's advices is more or less high. It is found that CBR is useful to the presented partner agent.

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