

Research on the Ways to Win in a Simple Poker Game

Anqi Xu*

Number One Middle School, Qingdao, China

*1712020121@stu.hrbust.edu.cn

Abstract. Poker is a popular card game as well as the foundation of a number of types of gambling. Since the variability of playing poker is high as a typical intellectual game, and the uncertainty and complexity is significant during the game, ways to win in poker games have always been widely discussed about. The aim of this essay is to use probabilities and statistics to calculate the probability that a player wins in a one-to-one poker game, and analyze the data. Then use methods such as combination and classification discussion to calculate the probability for a player to win as well as testifying the validity of the probability acquired by using different categories of experiments. Eventually, use the Kelly formula to calculate the percentage of the player's total chips that should be raised, hence to give an instruction to the player to make reasonable decisions during the game in order to maximize the profit. It can also provide methods to solving more complicated poker games and enhance the poker skills.

Keywords: Poker game, probability, the Kelly formula, raise.

1. Introduction

The game of poker originated in Italy in the 15th century, and by the 20th century the game of poker had become increasingly popular, and it was known as "the game of the thinking man". How to win and maximize the benefits of poker-based gambling games is the most concerned issue for the majority of players [1]. This problem has important research value in the fields of computer science, mathematics, and probability and statistics [2].

In the twenty twenties, von Neumann, the father of computers, and Aumann, a mathematician, proposed and proved the maximum-minimum theorem of zero-sum game between two people [3], which laid the cornerstone for the subsequent development of game theory. Subsequently, in 1994, von Neumann and economist Oskar Morgenstern co-authored Theory of Games and Economic Behavior, which marked the initial formation of modern system game theory [4]. In 1950, Nash proved the existence of equilibrium solutions in multi-person games in his paper Non-Cooperative Games and extended the maximum-minimum theorem to zero-sum games of multiple competing players, laying a solid foundation for the generalization of game theory [5]. In 2003, Billings et al. proposed the optimal strategy theory for the two-person Fixed Limit Hold'em problem [6]. In 2006, Sturtevant et al. further studied the two-person Fixed Limit Hold'em problem, combining opponent modeling and game tree search technology to achieve depth-first search in a reasonable time [7]. In 2015, Bowling et al. improved the basic CFR, proposed a new variant of the CFR+ algorithm, and cracked the winning method of heads-up limit Texas Hold'em (HULTH) for the first time [8, 9]. In 2018, Brown proposed a method for finite depth-first search in imperfect information games. Carnegie Mellon University (SMU) in the United States published remarkable research results in Science, the Texas Hold'em program Pluribus defeated human professional players in multiplayer no-limit Texas hold'em, which greatly shocked the academic community and all walks of life [10].

This article will take an in-depth look at a simple two-player poker game and propose a probabilistic-based solution. The research goal of this paper is to find out the probability that a player wins, and then calculate the percentage of the bet amount through the Kelly formula, so that the player can get the maximum profit after multiple bets.

A simple Pocker game is designed. The rules are shown below. Firstly, there are 52 cards in total (jockers are excluded), and 1player and 1 dealer can participate in the game. Secondly, player and dealer each acquire 2 cards at random, and they can only see the numbers on their own cards. After getting the sum of one's own cards, player and dealer may bet. Finally, showdown, the one with the

largest sum can get all the chips, odds ratio of the player is b, if sums of cards are the same, another hand. In order to maximize the profit, the participants need to calculate the expectation of winning, losing, and even. With the Kelly formula, the participants will be able to know the percentage of the total of chips that should be bet.

2. Methodology

Two cards are acquired at random, when $x + y > 13$, combinations are acquired and classification discussion can be used to calculate the probability of losing and even. Hence, indirect method is used to calculate the probability of winning. When $x + y \leq 13$, combinations are acquired discussion and classification discussion can be used to calculate the probability of winning with direct method. Then, the Kelly formula can be used to calculate the amount of chips to raise based on the probability of winning to ensure the player get the maximum profit.

2.1. Situation $x + y > 13$

In order to calculate the probability of losing, the discussion over the parity of $(x + y)$ and whether $x = y$ is needed. When $x \neq y$, $x + y$ is odd, the dealer's combinations of the numbers of the two cards in order to win are listed below.

$$\begin{array}{ccccccc} \{K, K\} & \{Q, Q\} & \cdots & \{x, x\} & \cdots & \{\frac{x+y+1}{2}, \frac{x+y+1}{2}\} & \\ \{K, Q\} & \{Q, J\} & \cdots & \{x, x-1\} & \cdots & & \\ \{K, J\} & \vdots & \cdots & \vdots & \cdots & & \\ \vdots & \{Q, x+y-11\} & \cdots & \{x, y+1\} & \cdots & & \\ \{K, x+y-12\} & & & & & & \end{array} \quad (1)$$

Since $x + y - 12 > 0$, therefore $x + y > 12$. The cases can be divide as:

Such as: $\{K, K\}, \{Q, Q\}, \cdots, 13 - \frac{x+y+1}{2} = \frac{25-x-y}{2}$ combinations in total.

Such as: $\{K, x\}, \{K, y\}, \cdots, 2(13 - x) + (x - y - 1) = 25 - x - y$ combinations in total.

One combination of $\{x, x\}$, such as: $\{K, Q\}\{K, J\}, \cdots (23 - x - y) + (21 - x - y) + \cdots + 2 = \frac{\frac{23-x-y}{2}(23-x-y+2)}{2} = \frac{(23-x-y)(25-x-y)}{4}$ combinations in total.

Using combinations to calculate the probability for the player to lose.

$$P_1 = P(\text{lose}) = \frac{\frac{25-x-y}{2}C_4^2 + (25-x-y)C_4^1C_3^1 + C_3^2 + \frac{(23-x-y)(25-x-y)}{4}C_4^1C_4^1}{C_{50}^2} = \frac{4(x+y)^2 - 207(x+y) + 2678}{1225} \quad (2)$$

When $x \neq y$, $x + y$ is even, the dealer's combinations of the numbers of the two cards in order to win are listed below.

$$\begin{array}{ccccccc} \{K, K\} & \{Q, Q\} & \cdots & \{x, x\} & \cdots & \{\frac{x+y}{2} + 1, \frac{x+y}{2} + 1\} & \\ \{K, Q\} & \{Q, J\} & \cdots & \{x, x-1\} & \cdots & \{\frac{x+y}{2} + 1, \frac{x+y}{2}\} & \\ \{K, J\} & \vdots & \cdots & \vdots & \cdots & & \\ \vdots & \{Q, x+y-11\} & \cdots & \{x, y+1\} & \cdots & & \\ \{K, x+y-12\} & & & & & & \end{array} \quad (3)$$

Since $x + y - 12 > 0$, therefore $x + y > 12$. The cases can be divide as:

Such as: $\{K, K\}, \{Q, Q\}, \cdots, 12 - \frac{x+y}{2} = \frac{24-x-y}{2}$ combinations in total.

Such as: $\{K, x\}, \{K, y\}, \cdots, 2(13 - x) + (x - y - 1) = 25 - x - y$ combinations in total.

One combination of $\{x, x\}$, such as: $\{K, Q\}\{K, J\}, \dots (23 - x - y) + (21 - x - y) + \dots + 1 = \frac{24-x-y}{2}(23-x-y+1) = \frac{(24-x-y)^2}{4}$ combinations in total. Using combinations to calculate the probability for the player to lose.

$$P_1 = P(\text{lose}) = \frac{\frac{24-x-y}{2}C_4^2 + (25-x-y)C_4^1C_3^1 + C_3^2 + \frac{(24-x-y)^2}{4}C_4^1C_4^1}{C_{50}^2} = \frac{4(x+y)^2 - 207(x+y) + 2679}{1225} \quad (4)$$

2.2. Calculate the Probability of Even

In order to calculate the probability of even, the discussion over the parity of $x + y$ and whether $x = y$ is needed. When $x \neq y$, $x + y$ is even, the dealer's combinations of the numbers of the two cards in order to win are listed below.

Such as: $\{K, x + y + 13\} \{Q, x + y - 12\} \dots \left\{\frac{x+y+1}{2}, \frac{x+y-1}{2}\right\}$. Since $x + y - 13 > 0$, therefore $x + y > 13$, using combinations to calculate the probability of even.

$$P_2 = P(\text{even}) = \frac{\left(14 - \frac{x+y}{2} - 1\right) \times C_4^1C_4^1 + C_3^1C_3^1 + C_4^2}{C_{50}^2} = \frac{8(24-x-y)+15}{C_{50}^2} = \frac{207-8(x+y)}{1225} \quad (5)$$

When $x+y$ is Even, the dealer's combinations of the numbers of the two cards in order to win are listed below.

Such as: $\{K, x + y - 13\} \{Q, x + y - 12\} \dots \left\{\frac{x+y}{2}, \frac{x+y}{2}\right\}$. Since $x + y - 13 > 0$, therefore $x + y > 13$. Using combinations to calculate the probability of even. Therefore $P_2 = P(\text{even}) = \frac{\left(14 - \frac{x+y}{2} - 2\right) \times C_4^1C_4^1 + C_3^1C_3^1 + C_4^2}{C_{50}^2} = \frac{8(24-x-y)+15}{C_{50}^2} = \frac{207-8(x+y)}{1225}$. When $x + y > 13$ $x \neq y$,

$$P_2 = P(\text{even}) = \begin{cases} \frac{209-8(x+y)}{1225}, & x + y \text{ is odd} \\ \frac{207-8(x+y)}{1225}, & x + y \text{ is even} \end{cases} \quad (6)$$

2.3. Situation $x = y$

When $x=y$, calculate the probability of losing and even respectively. The dealer's combinations of the numbers of the two cards in order to win are listed below.

$$\begin{array}{lll} \{K, K\} & \{Q, Q\} & \dots \{x + 1, x + 1\} \\ \{K, Q\} & \{Q, J\} & \dots \{x + 1, x\} \\ \{K, J\} & \vdots & \dots \\ \vdots & \{Q, 2x - 11\} & \\ \{K, 2x - 12\} & & \end{array} \quad (7)$$

Using combinations to calculate the probability for the player to lose and even respectively.

$$P_1 = P(\text{lose}) = \frac{(13-x)C_4^1C_2^1 + (13-x)C_4^2 + C_4^1 \times C_4^1(12-x)(13-x)}{C_{50}^2} = \frac{2(13-x)(103-8x)}{C_{50}^2} = \frac{16x^2 - 414x + 2678}{1225} \quad (8)$$

$$P_2 = P(\text{even}) = \frac{(13-x) \times C_4^1C_4^1 + C_2^2}{C_{50}^2} = \frac{16(13-x)+1}{C_{50}^2} = \frac{209-16x}{1225} \quad (9)$$

The conclusions of even and for the player to lose under different circumstances are shown below. Therefore when $x + y > 12$,

$$P_l = P(\text{lose}) = \begin{cases} \frac{4(x+y)^2 - 207(x+y) + 2678}{1225}, & x \neq y, x + y \text{ is odd} \\ \frac{4(x+y)^2 - 207(x+y) + 2679}{1225}, & x \neq y, x + y \text{ is even} \\ \frac{16x^2 - 414x + 2678}{1225}, & x = y \end{cases} \quad (10)$$

when $x + y > 13$,

$$P_2 = P(\text{even}) = \begin{cases} \frac{209-8(x+y)}{1225}, & x \neq y \text{ and } x+y \text{ is odd} \\ \frac{207-8(x+y)}{1225}, & x \neq y \text{ and } x+y \text{ is even} \\ \frac{209-16x}{1225}, & x = y \end{cases} \quad (11)$$

Calculating the probability of losing when $x > 12$, when $x > 13$, calculate the probability of even. Hence get the common parts of the two solutions. Therefore, when $x + y > 13$, $P = P(\text{win}) = 1 - P(\text{lose}) - P(\text{even}) = 1 - P_1 - P_2$.

$$P = P(\text{win}) = \begin{cases} \frac{-4(x+y)^2+215(x+y)-1661}{1225}, & x \neq y \text{ and } x+y \text{ is odd} \\ \frac{-4(x+y)^2+215(x+y)-1662}{1225}, & x \neq y \text{ and } x+y \text{ is even} \\ \frac{-16x^2+430x-1662}{1225}, & x = y \end{cases} \quad (12)$$

The probabilities for the player to win when $x + y > 13$ under three different circumstances are acquired with indirect method.

2.4. Situation $x + y \leq 13$

When $x + y \leq 13$, combinations are acquired discussion and classification can be used to calculate the probability of winning with direct method. In order to calculate the probability of winning, the discussion over the parity of $(x+y)$ and whether $x = y$ is needed.

When $x \neq y$, $x + y$ is odd, the dealer's combinations of the numbers of the two cards in order to win are listed below.

$$\begin{array}{ccccccc} \{A, A\} & \{2, 2\} & \cdots & \{x, x\} & \cdots & \left\{ \frac{x+y-1}{2}, \frac{x+y-1}{2} \right\} \\ \{A, 2\} & \{2, 3\} & \cdots & \{x, x+1\} & \cdots & \\ \{A, 3\} & \vdots & \cdots & \vdots & \cdots & \\ \vdots & \{2, x+y-3\} & \cdots & \{x, y-1\} & \cdots & \\ \{A, x+y-2\} & & & & & \end{array} \quad (13)$$

Using combinations to calculate the probability for the player to win.

$$P = P(\text{win}) = \frac{\frac{x+y-3}{2} C_4^2 + (x+y-3) C_4^1 C_3^1 + C_3^2 + \frac{(x+y-5)(x+y-3)}{4} C_4^1 C_4^1}{C_{50}^2} = \frac{4(x+y)^2 - 17(x+y) + 18}{1225} \quad (14)$$

When $x \neq y$, $x + y$ is even, the dealer's combinations of the numbers of the two cards in order to win are listed below.

$$\begin{array}{ccccccc} \{A, A\} & \{2, 2\} & \cdots & \{x, x\} & \cdots & \left\{ \frac{x+y}{2} - 1, \frac{x+y}{2} - 1 \right\} \\ \{A, 2\} & \{2, 3\} & \cdots & \{x, x+1\} & \cdots & \left\{ \frac{x+y}{2} - 1, \frac{x+y}{2} \right\} \\ \{A, 3\} & \vdots & \cdots & \vdots & \cdots & \\ \vdots & \{2, x+y-3\} & \cdots & \{x, y-1\} & \cdots & \\ \{A, x+y-2\} & & & & & \end{array} \quad (15)$$

Using combinations to calculate the probability for the player to win.

$$P = P(\text{win}) = \frac{\frac{x+y-4}{2} C_4^2 + (x+y-3) C_4^1 C_3^1 + C_3^2 + \frac{(x+y-4)^2}{4} C_4^1 C_4^1}{C_{50}^2} = \frac{4(x+y)^2 - 17(x+y) + 19}{1225} \quad (16)$$

When $x = y$, the dealer's combinations of the numbers of the two cards in order to win are listed below.

$$\begin{array}{llll}
 \{A, A\} & \{2, 2\} & \cdots & \{x-1, x-1\} \\
 \{A, 2\} & \{2, 3\} & \cdots & \{x-1, x\} \\
 \{A, 3\} & \vdots & \cdots & \\
 \vdots & \{2, 2x-3\} & \cdots & \\
 \{A, 2x-2\} & & &
 \end{array} \quad (17)$$

Using combinations to calculate the probability for the player to win.

$$P = P(\text{win}) = \frac{(x-1)C_4^1 C_2^1 + (x-1)C_4^2 + C_4^1 \times C_4^1 (x-1)(x-2)}{C_{50}^2} = \frac{16x^2 - 34x + 18}{1225} \quad (18)$$

Therefore, when $x + y \leq 13$,

$$P = P(\text{win}) = \begin{cases} \frac{4(x+y)^2 - 17(x+y) + 18}{1225}, & x \neq y, x+y \text{ is odd} \\ \frac{4(x+y)^2 - 17(x+y) + 19}{1225}, & x \neq y, x+y \text{ is even} \\ \frac{16x^2 - 34x + 18}{1225}, & x = y \end{cases} \quad (19)$$

2.5. Calculate the Ratio of Capital

The Kelly formula can be used to calculate the amount of chips to raise based on the probability of winning to ensure the player get the maximum profit. Kelly formula: $f^* = \frac{bp-q}{b}$, b is the odds ratio, p is the probability of winning and $q=1-p$, f^* is the ratio of capital to be invested. By substituting the probability of winning, p , that was calculated above, the chips that should be bet by player can be decided, hence to ensure the player with the maximum profit.

3. Empirical Examples

When $x + y > 13$,

$$P = P(\text{win}) = \begin{cases} \frac{-4(x+y)^2 + 215(x+y) - 1661}{1225}, & x \neq y \text{ and } x+y \text{ is odd} \\ \frac{-4(x+y)^2 + 215(x+y) - 1662}{1225}, & x \neq y \text{ and } x+y \text{ is even} \\ \frac{-16x^2 + 430x - 1662}{1225}, & x = y \end{cases} \quad (20)$$

The probabilities for the player to win when $x + y > 13$ under three different circumstances are acquired with indirect method. When $x + y \leq 13$,

$$P = P(\text{win}) = \begin{cases} \frac{4(x+y)^2 - 17(x+y) + 18}{1225}, & x \neq y, x+y \text{ is odd} \\ \frac{4(x+y)^2 - 17(x+y) + 19}{1225}, & x \neq y, x+y \text{ is even} \\ \frac{16x^2 - 34x + 18}{1225}, & x = y \end{cases} \quad (21)$$

The probabilities for the player to win when $x + y \leq 13$ under three different circumstances are acquired with indirect method. Then, the Kelly formula can be used to calculate the amount of chips to raise based on the probability of winning to ensure the player get the maximum profit. By substituting the probability of winning, with the Kelly formula, the amount of chips that should be bet in order to get the maximum profit can be decided.

3.1. The Cards Got are J and 7

Case 1. Let $x = 11, y = 7$, $x + y = 11 + 7 = 18$ which is even.

Method 1:

$$\begin{array}{cccc}
 \{K, K\} & \{Q, Q\} & \{J, J\} & \{10, 10\} \\
 \{K, Q\} & \{Q, J\} & \{J, 10\} & \{10, 9\} \\
 \{K, J\} & \vdots & \{J, 9\} & \\
 \vdots & \{Q, 7\} & \{J, 8\} & \\
 \{K, 6\} & & &
 \end{array} \quad (22)$$

We get $P_1 = P(\text{lose}) = \frac{3C_4^2 + 7C_4^1C_3^1 + C_3^2 + 9C_4^1C_4^1}{C_{50}^2} = \frac{249}{1225}$, and $P_2 = P(\text{even}) = \frac{3C_4^1 + C_4^2 + C_3^1C_3^1}{C_{50}^2} = \frac{63}{1225}$.
Substitute $x = 11, y = 7$ into the formulae $P_1 = P(\text{lose}) = \frac{16xy - 210x - 236y + 3099}{C_{50}^2} = \frac{249}{1225}$, and $P_2 = P(\text{even}) = \frac{8(24-x-y)+15}{C_{50}^2} = \frac{63}{1225}$. The result supports the formulae.

Method 2:

$$\begin{array}{cccccccc}
 \{A, A\} & \{2, 2\} & \{3, 3\} & \{4, 4\} & \{5, 5\} & \{6, 6\} & \{7, 7\} & \{8, 8\} \\
 \{A, 2\} & \{2, 3\} & \{3, 4\} & \{4, 5\} & \{5, 6\} & \{6, 7\} & \{7, 8\} & \{8, 9\} \\
 \vdots & \vdots & \vdots & \vdots & \vdots & \vdots & \{7, 9\} & \\
 \{A, K\} & \{2, K\} & \{3, K\} & \{4, K\} & \{5, Q\} & \{6, J\} & \{7, 10\} &
 \end{array} \quad (23)$$

We get $P = P(\text{win}) = \frac{7C_4^2 + 15C_4^1C_3^1 + C_3^2 + 43C_4^1C_4^1}{C_{50}^2} = \frac{913}{1225}$. Substitute $x = 11, y = 7$ into the formulae $P = P(\text{win}) = \frac{-4(x+y)^2 + 215(x+y) - 1661}{C_{50}^2} = \frac{913}{1225}$. The result supports the formulae. Since $\frac{249}{1225} + \frac{63}{1225} + \frac{913}{1225} = 1$. Therefore, $P(\text{win}) + P(\text{even}) + P(\text{lose}) = 1$, the conclusion is correct.

3.2. The Cards Got are Q and J

Case 2. Let $x = 12, y = 11, x + y = 12 + 11 = 23$ which is odd. Then $P_1 = P(\text{lose}) = \frac{C_4^2 + C_3^2 + 2C_4^1C_3^1}{C_{50}^2} = \frac{33}{1225}$, $P_2 = P(\text{even}) = \frac{C_4^1C_4^1 + C_3^1C_3^1}{C_{50}^2} = \frac{25}{1225}$. Substitute $x = 12, y = 11$ into the formulae $P_1 = P(\text{lose}) = \frac{16xy - 210x - 236y + 3099}{C_{50}^2} = \frac{33}{1225}$, $P_2 = P(\text{even}) = \frac{8(25-x-y)+9}{C_{50}^2} = \frac{25}{1225}$.

3.3. The Cards Got are Q and Q

Case 3. Let $x = y = 12, x + y = 12 + 12 = 24$ which is even. Then $P_1 = P(\text{lose}) = \frac{C_4^2 + C_4^1C_2^1}{C_{50}^2} = \frac{14}{1225}$, $P_2 = P(\text{even}) = \frac{C_2^2 + C_4^1C_4^1}{C_{50}^2} = \frac{17}{1225}$.

Substitute $x = y = 12$ into the formulae $P_1 = P(\text{lose}) = \frac{16xy - 210x - 236y + 3099}{C_{50}^2} = \frac{14}{1225}$, $P_2 = P(\text{even}) = \frac{8(24-x-y)+15}{C_{50}^2} = \frac{17}{1225}$.

3.4. The Cards Got are J and J

Case 4. Let $x = y = 11, x + y = 22$ which is even. Then $P_1 = P(\text{lose}) = \frac{2C_4^2 + 2C_4^1C_2^1 + 2C_4^1C_4^1}{C_{50}^2} = \frac{60}{1225}$, $P_2 = P(\text{even}) = \frac{C_2^2 + 2C_4^1C_4^1}{C_{50}^2} = \frac{33}{1225}$.

Substitute $x = y = 11$ into the formulae $P_1 = P(\text{lose}) = \frac{16xy - 210x - 236y + 3099}{C_{50}^2} = \frac{60}{1225}$, $P_2 = P(\text{even}) = \frac{8(24-x-y)+15}{C_{50}^2} = \frac{33}{1225}$. The result supports the formulae.

4. Conclusion

Methods such as combination and classification discussion are used to calculate the probability for a player to win and different categories of experiments are used to testify the validity of the probability

acquired. And the Kelly formula is used to assist the player to calculate the ratio of capital to be invested precisely, hence to give an instruction to the player to make reasonable decisions during the game in order to maximize the profit. This essay provides a way to raise based on probability and statistics through the researches on the poker game. The results can calculate the exact probability for a player to win with formulae and is of significant value to understanding the importance of poker games. It can also provide methods to solving more complicated poker games and enhance the poker skills. The main issue of this essay is that it only focuses on an easy type of poker game and does not have a discussion about other types of poker game. The paper has quite a few directions worthy of further exploring, including but not limiting to making the rules of game more complex and enlarging number of players.

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