# Blackjack Strategy Simulation Report

Julie Chen


## Abstract

Blackjack, also known as Twenty-One, is a popular casino card game played with at least one standard 52-card deck. As with all casino games, the odds of winning over time are stacked against the player. The win rates of several different basic Blackjack strategies using six decks of cards over ten thousand rounds of Blackjack were explored and compared. The goal of the simulation was to identify the best strategy to minimize betting losses. Python programming was used to construct the simulation of a Blackjack table with multiple players each betting the same amount of money. Utilizing the basic strategies provided by Bicycle Cards and Blackjack Apprenticeship resulted in the highest win ratios, but ultimately still yield losses in money over time against the House. Further investigation reveals differences in performance based on players' starting hands, dealer upcards, and the decision to hit or stand at a given point in the game.


## 1. Problem Statement

### *1.1 Blackjack Overview*

Every game that is played at a casino has a statistical probability against the player winning. With a house advantage in place, this means that the longer a player plays against the casino, the more likely the player is to lose money. [1] Although the number of decks, shuffling, or betting rules may differ amongst casinos, the objective of Blackjack and its basic rules are generally the same. The goal of the player is to score higher than the dealer by getting as close to a score of 21 as possible, without going over 21, and lose as little money as possible. Below are some basic game terminologies that will be used hereafter.

- Hit: A player may choose to be dealt another card to increase the score in their hand.
- Stand: A player may choose to keep their current score without adding another card.
- Bust: A player busts when their score is over 21.
- Ten-card: Any card with a value of 10. {10, Jack, Queen, King}
- Soft: A player's hand contains an Ace whose value could be counted as 11 or 1, without either score causing the player to bust. The soft score is the higher of the two totals.
- Hard: The hard score is the lower of the two totals if an Ace is in hand, otherwise it is just the score itself.
- Natural: A player's first two cards equal 21, comprised of an Ace and ten-card.

### *1.2 Rules and Game Setup*

[1] Neiger, Chris. 2020. "Casino Stats: Why Gamblers Rarely Win." Investopedia. October 28, 2020. https://www.investopedia.com/financial-edge/0910/casino-stats-why-gamblers-rarely-win.aspx.

The rules and setup of Blackjack used for this simulation are a simplified version of the rules and setup found on the Bicycle Cards website[2]. This simulation does not include player actions such as "double down" or "split.

- All numbered cards have the same value as their number.
- All face cards {Jack, Queen, King} have a value of 10.
- Ace cards can have a value of 1 or 11.
- All players at the table play against the dealer.
- Every round starts with the same number of players and a newly shuffled deck(s).
- Every player bets the same amount at the start ($10).

To start the game, each player places a bet. The dealer deals two cards to each player, and then two cards to himself. The first card the dealer gives himself will be face up, and the other will remain face down. All players look at their cards and can then choose to hit or stand based on a set of decision rules detailed in the Methodology section. After all players stand, the dealer reveals the face-down card and proceeds to hit or stand following the dealer rules. Each player compares their own score to the dealer and winnings are determined in the following order:

- If a player busts, they lose their bet.
- If a player has a natural and the dealer does not, the player wins their bet. The player's bet is returned and they earn an additional 1.5 times their bet.
- If a player and dealer both have naturals, they tie. The bet is returned to the player.
- If the dealer has a natural, but the player does not, then the player loses their bet.
- If the dealer busts or if the player has a higher score than the dealer, the player's bet is returned and they earn an additional amount equal to their bet.
- If a player has a lower score than the dealer, they lose their bet.
- If a player and the dealer have the same score, they tie. The player's bet is returned.

## 2. Methodology

### *2.1 Programming*

All programming and analysis were performed in Python via Google Colab. A random seed was used at the start of the program for the reproducibility of results and future analysis. A direct link to the project can be found in Appendix A and the code file is available in the project submission folder.

### *2.2 Strategies Implemented*

To maximize player profits—or equivalently minimize losses—at a Blackjack table, simulation techniques were employed to demonstrate the effectiveness of five basic Blackjack strategies: 1) copying the dealer's decision rules; 2) always choosing to hit until reaching a reasonably high score; 3) randomly choosing hit or stand with equal probability; 4) following basic strategy from the Bicycle Cards website; and 5) following basic strategy from strategy charts on Blackjack Apprenticeship. These strategies are summarized in Table 1 below.

[2] "Blackjack." n.d. Bicyclecards.com. https://bicyclecards.com/how-to-play/blackjack.

| Strategy: | Description: |
|---|---|
| Dealer | Player uses the same set strategy as the Blackjack dealer.<br>▪ Hit if hand value is less than 17.<br>▪ Hit if hand value is soft 17, otherwise stand. |
| Simple | Player hits if their hand value is less than 17, otherwise stands. |
| Random | Player flips a fair coin to decide if they hit or stand. |
| Bicycle | Player looks at dealer's upcard.<br>▪ If hand value is soft, hit until hand value is 18 or higher.<br>▪ If hand value is less than 17 and dealer's upcard is one of {7, 8, 9, ten-card, Ace}, hit until hand value is 17 or higher.<br>▪ If hand value is less than 17 and dealer's upcard is one of {4, 5, 6}, hit until hand value is 12 or higher.<br>▪ If hand value is less than 17 and dealer's upcard is one of {2, 3}, hit until hand value is 13 or higher. |
| Chart | Player looks at dealer's upcard and follows a modified version of a popular strategy chart from Blackjack Apprenticeship.[3] [Appendix B] |

*Table 1: Basic Blackjack strategies implemented*

To test the effectiveness of each strategy, a Blackjack game table was created and initialized with one dealer and five players. Each player plays one of the basic strategies listed above, respectively. As mentioned in §1.2 Rules and Game Setup, some simplifications were made regarding bet amounts and deck shuffling. In particular, due to the fact that there are five players at the table whose card draws may affect what other players or the dealer receives, it must be stated that this simulation does not replicate five independent single-player Blackjack games against the dealer. Despite this fact, a simulation with five simultaneous players more accurately simulates a real-life game of Blackjack at a casino table, where players are pitting their own strategies against the dealer. Direct comparisons can then be made between the performances of each Blackjack strategy over the course of ten thousand rounds played in a "closer-to-real-life" scenario where one may not be the only player at the table.

## 3. Evaluation and Results

### *3.1 Investigating Win Ratios*

For this experiment, a "win" and "loss" is defined as stated in the rules in §1.2. A "tie" is not counted in the win ratio calculations here because a tie does not result in the gain or loss of money for the player. A win ratio is therefore defined per player as:

$$player\ win\ ratio\ = \frac{\#\ \text{rounds won}}{\#\ \text{rounds won}\ +\ \#\ \text{rounds lost}}$$

[3] Jones, Colin. "Blackjack Strategy Charts - How to Play Perfect Blackjack." 2017. Blackjack Apprenticeship. 2017. https://www.blackjackapprenticeship.com/blackjack-strategy-charts/.

Using a random seed for reproducibility and a game table with one dealer and five players as mentioned in setup, the following win ratios over 10,000 games were observed.

| Player | Strategy | Win Ratio | Net Earnings |
|---|---|---|---|
| 0 | Dealer | 0.4489 | -$7265 |
| 1 | Simple | 0.4541 | -$6005 |
| 2 | Random | 0.2795 | -$40160 |
| 3 | Bicycle | 0.4764 | -$1765 |
| 4 | Chart | 0.4770 | -$1680 |

*Table 2: Win ratios and net earnings per strategy after 10,000 rounds of Blackjack.*

The win ratios for the Bicycle and Chart strategies are very similar. In fact, in other random trials without a set seed, it was observed that sometimes the Bicycle strategy win ratio would be slightly higher than the Chart strategy win ratio, and other times vice-versa. Since their overall performances seem to be about the same, either one seems to be a reasonable choice for a player to use compared to the Dealer, Simple, or Random strategies. A player should absolutely not use the Random strategy, as they would be expected to lose far more often than their peers using any of the alternative strategies.

### *3.2 Net Earnings and Strategies that Minimize Losses*

The claim that the best way of earning money through casino gambling is to stay away from the casino can be verified through repeated runs of the game via simulation. It can be shown mathematically and through various runs of the Blackjack simulation that playing more games would lead to more money lost over time. To demonstrate this, one can change the integer value of `NUM_ROUNDS` and look at how much money a player has earned or lost over the course of that many rounds of Blackjack.

Reviewing the values in the Net Earnings column of Table 2, it appears that the Chart strategy loses the player the least amount of money after 10,000 rounds of Blackjack, with the Bicycle strategy at a close second. This result makes sense following the win ratio investigation above. Therefore, to lose the least amount of money, a person should play as few games of Blackjack as possible, if not stay away from casinos altogether. If for whatever reason they find themselves trapped in the Lotus Hotel and Casino[4] where the rules of Blackjack are the same as those of this experiment, that person should use the Chart strategy to be in the least amount of debt after escaping.

### *3.3 Starting Hand Scores*

Further investigation into the effectiveness of each strategy was done based on the starting hand of each player to begin answering the question: Can some strategies be better than others in specific situations? The starting hands for each player across all 10,000 rounds were kept to track whether the player eventually wins the round against the dealer with that given hand. After grouping by player strategy, a win rate was calculated for each player's starting hand value by dividing the number of resulting wins by the total number

[4] The Lotus Hotel and Casino is a fictional casino in the Percy Jackson and the Olympians book series that is based on the myth of the Lotus Tree in Homer's Odyssey. When people are inside, they never want to leave and time never seems to pass.

of rounds that were played using a starting hand with the same value. The resulting simulated win likelihoods are shown in Figure 1.

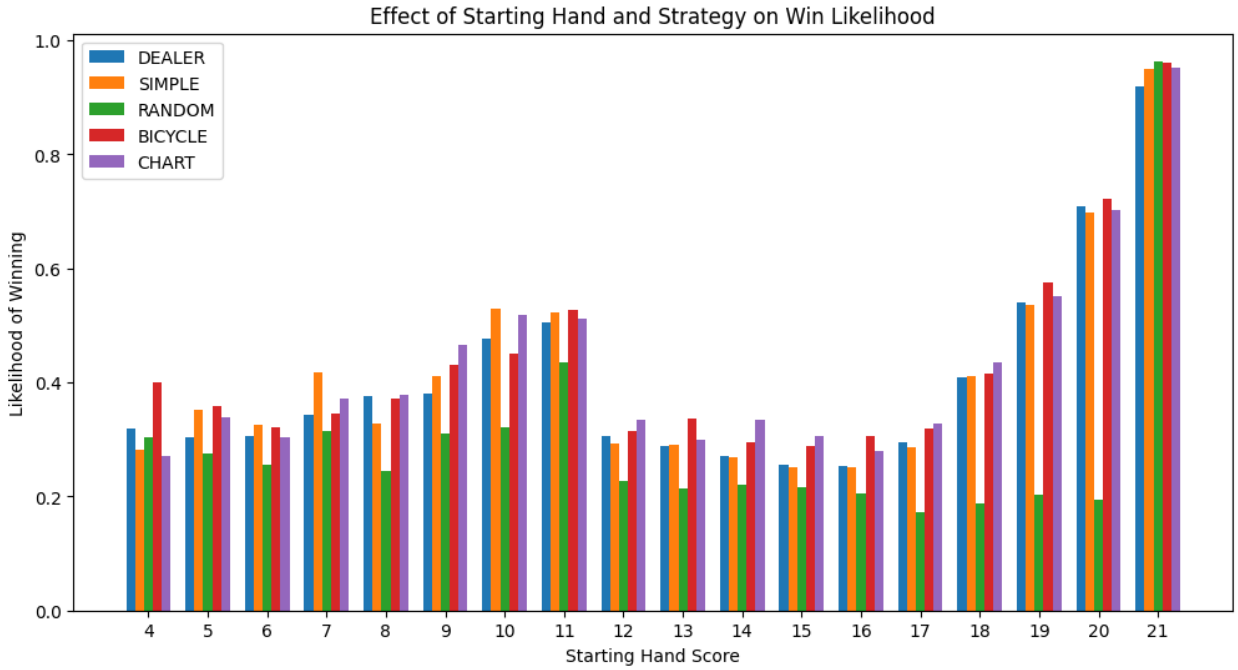


*Figure 1: Graph of win likelihoods per strategy, based on starting hand score.*

There is a clear pattern in Figure 1 demonstrating that starting hand values between 12 and 17 have a lower likelihood of winning. In general, a Random strategy will give you a low likelihood of winning regardless of your starting hand, unless the player starts with a natural. All naturals have a very high likelihood of winning, regardless of strategy, but a starting score of 19 or 20 are also quite good for any non-Random strategy. It is important to emphasize that the win rate of a natural is not 100% due to potential ties with the dealer.

### *3.4 Dealer Upcards*

Besides exploring each player's starting hands, it is also reasonable to assume that the dealer's upcard will affect a player's chance of winning the round. To examine the effect of the dealer upcard on player win likelihoods, a similar method was employed as in §3.3. The value of the dealer upcard was stored to determine whether a player won or lost against the dealer that round given said upcard. For each player strategy, a win rate was calculated by dividing the number of rounds where the player won against the dealer with a given upcard by the total number of rounds where the dealer had that upcard. A bar chart (Figure 2) was generated to illustrate the results.

It can be seen that all five strategy performances fluctuate in a similar manner across the different dealer upcard values, with the Random strategy win likelihoods consistently lower than 0.35 across all dealer upcard categories. Regardless of strategy, players have a very low chance of winning if the dealer upcard is an Ace, and a reasonably fair chance of winning if the dealer upcard is a 4, 5, or 6. With the Bicycle and Chart

strategies, the player's chances of winning go above 0.5 for dealer upcard values of 3, 4, 5, and 6.

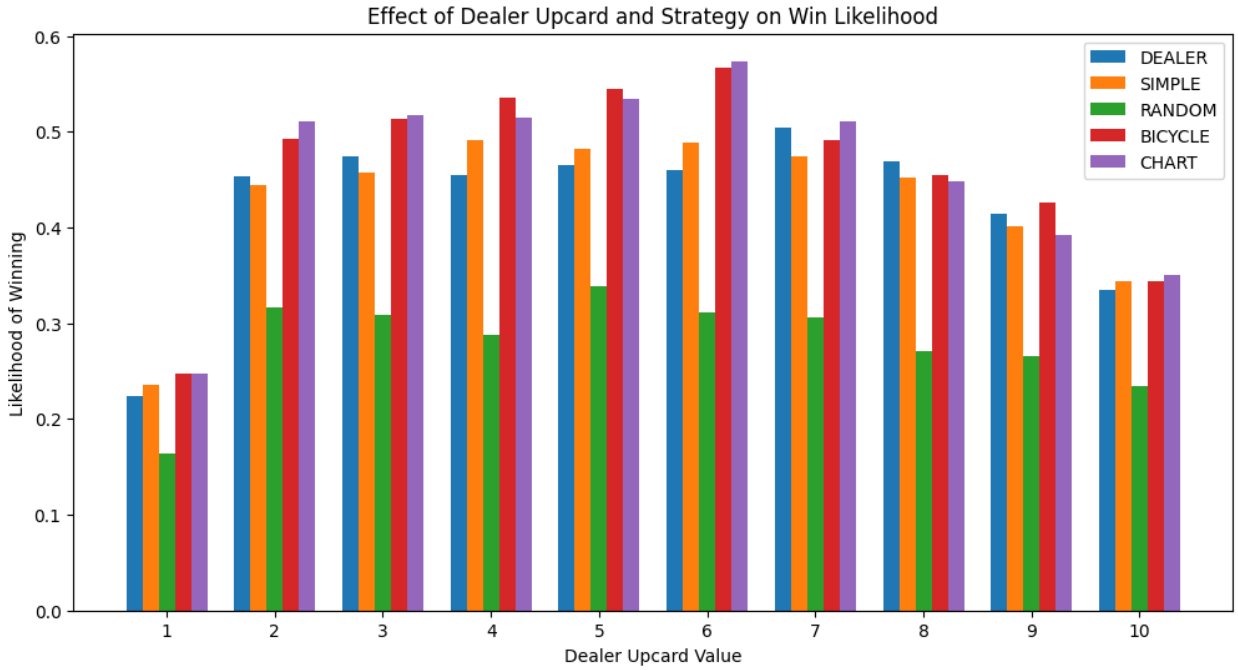


*Figure 2: Graph of player win likelihoods per strategy, based on dealer's upcard.*

### *3.5 Hit versus Stand Decision*

The earlier analyses done in §3.3 and §3.4 beg the question: Why do the Bicycle and Chart strategies outperform the others? To research the basis for the basic Blackjack strategy decisions, win likelihoods for a player at every stage of their hand can be checked to determine if it is better to hit or stand at the given state of the game. These likelihoods are then visualized on a line graph to highlight any key deciding factors for winning Blackjack at each hand.

A new game with a single player and a single deck was instantiated to generate chains of cards in a player's hand, supposing that the player's decision strategy was to hit until they bust. The game is simulated 10,000 times, and then win percentages are calculated based on what the end result of the round would be if the player had chosen to hit or stand. With the addition of Ace cards having a value of 1 or 11 at any point in the game, a distinction was made between current hands that are "hard" and hands that are "soft," so each hard or soft win percentage is calculated separately. Table 3 displays the possible combinations of score type (hard or soft) and player decisions.

| Score Type/ Decision | Hit | Stand |
|---|---|---|
| Hard | **Hard Hit** | **Hard Stand** |
| Soft | **Soft Hit** | **Soft Stand** |

*Table 3: Possible player decisions based on hand score type.*

Hence, after determining whether the total value of the cards in their hand is hard or soft, each player would then make a decision to hit or stand based on the simulated results stored in each of the player decision categories in Table 3. The graphed results are presented in Figure 3 below.

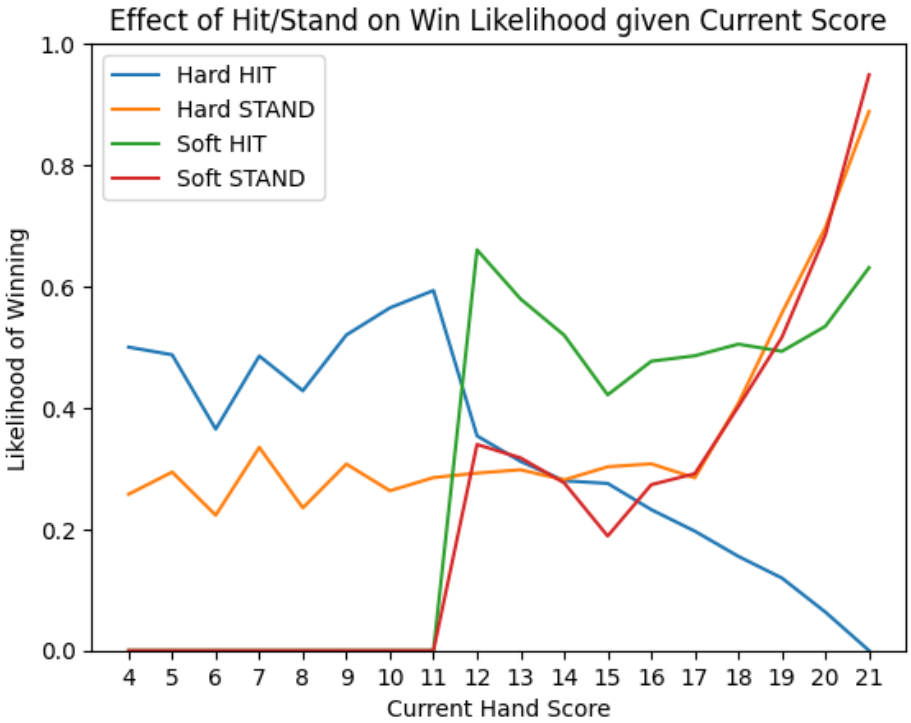


*Figure 3: Graph of win likelihood per hit/stand decision based on current hand score.*

Following the blue line that demonstrates the probability of winning if a player proceeds to hit at their current hard hand value, choosing to hit after a hand score of 12 only seems to decrease the likelihood of winning. This observation aligns with the third bullet point of the Bicycle strategy in Table 1. The orange and red stand decision lines show increased likelihoods of winning by choosing to stand at hand values of above 17—regardless of whether the hand is hard or soft—justifying both the Dealer and Simple strategies as well. An interesting observation can also be made when comparing Figure 3 with Figure 1. Both figures illustrate a decrease in (or low) likelihood of winning when the value of the cards in a player's hand falls between 12 and 17. Lastly, Figure 3 implies that a player should always hit if their current hand score is 10 or under, and if the current hand score is exactly a soft 12, hitting yields the highest chance of winning in that specific scenario.

**4. Conclusion**

In conclusion, this Blackjack experiment was completed with several modifications and/or simplifications to the game setup and rules. The results over 10,000 replications demonstrates that the only way to maximize player profits over the course of many games using this setup is to not play at all. As (presumably) novice players who do not employ card counting methods continue to play at a disadvantage against the House, certain basic

strategies like the ones presented on the Bicycle Cards or Blackjack Apprenticeship websites will more likely mitigate the House edge better than copying the dealer, simply hitting until reaching a score of 17 or greater, or playing randomly.

Various effects on a player's likelihood of winning were explored, such as the player's starting hand, the dealer's upcard, and the decision to hit or stand at any given point in the player's turn. There is a disadvantage to the player if their starting hand score lies between 12 and 17. This makes sense, as a starting hand between 12 and 17 gives the player a smaller chance to hit without busting. The greatest disadvantage to the player occurs if the dealer's upcard is an Ace, with the player's win likelihood being only approximately 25% at best. If a player's hand is hard, they have the best chances of winning by hitting if the current hand score is 10 or under, and standing if the current hand score is above 17. Otherwise, if the player's hand is soft, the player should always hit if the current hand score is between 12 and 17, inclusive. Standing if the current hand score is above 17 will yield the best results. At exactly a soft score of 12, one hit followed by standing is the recommended decision.

Future exploration of winning Blackjack strategies could include the addition of "double down" and "split" decisions for the player. Results can then be compared against the recommendations of the Blackjack Apprenticeship strategy charts and optimal strategies can be tuned to see if players can perform better than they would if they followed the chart recommendation. Another consideration would be to follow the standard casino shuffling rules, which is only to shuffle when the remaining deck reaches a certain number of cards, also known as the shoe. This will help illuminate card-counting strategies that players could employ to better maximize their earnings at the casino. Such a study would then also require a dynamic betting model, which was not employed here.

> Stephen Falken: *The whole point was to find a way to practice nuclear war without destroying ourselves. To get the computers to learn from mistakes we couldn't afford to make. Except, I never could get [WOPR] to learn the most important lesson.*
>
> David Lightman*: What's that?*
>
> *Stephen Falken: Futility. That there's a time when you should just give up.*

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> WOPR: *A strange game. The only winning move is not to play. How about a nice game of chess?*
>
> ~*WarGames* (1983)

**Appendix A:** Google Colab Project Link
https://colab.research.google.com/drive/163mfagfz_ieEOn1kJ9wipnyntGa9Z0U?usp=sharing

**Appendix B: Blackjack Strategy Chart, modified from Blackjack Apprenticeship**

**Hard Totals**

| | Dealer Upcard | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | **2** | **3** | **4** | **5** | **6** | **7** | **8** | **9** | **"10"** | **A** |
| **≥ 17** | **S** | **S** | **S** | **S** | **S** | **S** | **S** | **S** | **S** | **S** |
| **16** | **S** | **S** | **S** | **S** | **S** | **H** | **H** | **H** | **H** | **H** |
| **15** | **S** | **S** | **S** | **S** | **S** | **H** | **H** | **H** | **H** | **H** |
| **14** | **S** | **S** | **S** | **S** | **S** | **H** | **H** | **H** | **H** | **H** |
| **13** | **S** | **S** | **S** | **S** | **S** | **H** | **H** | **H** | **H** | **H** |
| **12** | **H** | **H** | **S** | **S** | **S** | **H** | **H** | **H** | **H** | **H** |
| **≤ 11** | **H** | **H** | **H** | **H** | **H** | **H** | **H** | **H** | **H** | **H** |

**Soft Totals**

| | Dealer Upcard | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | **2** | **3** | **4** | **5** | **6** | **7** | **8** | **9** | **"10"** | **A** |
| **≥ 19** | **S** | **S** | **S** | **S** | **S** | **S** | **S** | **S** | **S** | **S** |
| **18** | **S** | **S** | **S** | **S** | **S** | **S** | **S** | **H** | **H** | **H** |
| **≤ 17** | **H** | **H** | **H** | **H** | **H** | **H** | **H** | **H** | **H** | **H** |

**References**


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