

# Knowledge-Based Systems Final Report

## GTO Poker Bot: A Knowledge-Based Approach to Optimal Poker Strategy

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### 1. Introduction

Our GTO Poker Bot tackles the challenge of finding an optimal poker strategy using a knowledge-based approach inspired by game theory optimal (GTO) principles. The bot simulates human-like gameplay by interpreting the game state visually from the poker client and clicking buttons in the browser to play. It includes two different agent types: a fixed strategy agent based on GTO principles and a Deep Q-Network (DQN) agent that attempts to learn through self-play.

We chose this project to explore how AI techniques can be applied to the complex domain of poker, which, unlike games like chess and Go, remains an unsolved challenge for AI. Poker involves elements of imperfect information, stochastic events, and intricate game-theoretic considerations, making it a promising and engaging domain for AI research.

The bot is implemented in Python and designed to be compatible with various online poker platforms. It leverages the GPT-V model to interpret the game state from visual screenshots. The codebase has a modular architecture, with the logic for the fixed strategy agent located in `fixed.py` and the DQN agent in `dqn_agent.py`. Key parameters of the poker environment include a 52-card deck, predetermined starting stack sizes for each player, and defined small/big blind amounts.

We ran a series of 1000 simulated poker hands pitting the fixed strategy agent, DQN agent, and a random agent against each other. The fixed strategy agent emerged as the decisive winner, prevailing in 927 hands. The DQN agent managed to win 51 hands, while the random agent won only 6. There were 16 hands that resulted in ties. These results demonstrate the superiority of the fixed strategy agent, which leverages game theory optimal principles, over the learning-based DQN approach and random play. However, the relatively poor performance of the DQN agent points to the limitations and challenges of learning effective strategies in this highly complex problem domain.

### 2. Problem Specification

The GTO Poker Bot project addresses the challenge of creating an AI agent that can play poker optimally by visually interpreting the game state and taking actions through a web browser, simulating human play. Poker presents unique difficulties for AI due to its elements of imperfect information, stochastic events, and the need for complex strategic reasoning.

Poker involves hidden information (opponents' private cards), which makes it challenging to determine the optimal strategy. The game also includes random events in the form of card dealing, requiring the AI to reason under uncertainty. Furthermore, poker demands sophisticated strategic thinking, including the ability to bluff, model opponents, and adapt to changing game dynamics.

The main challenges in developing a poker AI include:

1. **Handling imperfect information:** The AI must make decisions based on incomplete knowledge of the game state, considering the range of possible opponent holdings and strategies.
2. **Dealing with stochastic events:** The random dealing of cards introduces uncertainty, requiring the AI to reason probabilistically and adapt its strategy accordingly.

3. **Modeling opponents:** To make optimal decisions, the AI must be capable of inferring opponents' likely holdings and strategies based on their actions.
4. **Developing a robust and adaptive strategy:** The AI needs to employ a strategy that is effective against a wide range of opponent playing styles and able to adjust as the game progresses.
5. **Interacting with the environment:** The AI must be able to interpret the game state visually and execute actions through a web browser interface, simulating human interaction with the poker platform.

While significant progress has been made in poker AI, with notable achievements like Libratus, Pluribus, and DeepStack (more on this within the next section), existing approaches often rely on computationally intensive algorithms and require direct access to the game state, making them unsuitable for deployment in real-world online poker environments.

Our GTO Poker Bot project aims to tackle these challenges by developing an AI agent that can learn and execute optimal strategies in a human-like manner, interacting with the poker platform through visual interpretation and simulated actions through clicking buttons in the browser. Our project explores the potential of combining knowledge-based approaches, such as a fixed strategy based on game-theoretic principles, with reinforcement learning techniques to create an effective and adaptable poker AI.

### Tools and Starting Points

The project leverages TensorFlow for implementing the DQN agent and GPT-V for interpreting the game state from screenshots. The fixed strategy agent [fixed.py] and the DQN agent [dqn\_agent.py] serve as the core components, with the operational framework [play.py] enabling interaction with online poker games. We used the framework self-operating computer [1] by HyperwriteAI as the basis for creating the autonomous mouse-clicking part of our project. We initially tried existing libraries such as NeuronPoker, PokerPy, and PokerStove but they were all outdated and not maintained, so we found it faster to create our own.

### PEAS

- **Performance:** Success is measured by the agent's ability to win hands and maximize earnings over time.
- **Environment:** Online poker platforms, characterized by varying game states, opponent strategies, and the visual presentation of information.
- **Actuators:** Actions within the game, such as fold, call, and raise, executed through simulated mouse clicks and keyboard inputs.
- **Sensors:** Screenshots of the game, processed and interpreted to understand the current state of the board and make decisions.

### Game Rules and Parameters

Poker, specifically the no-limit Texas Hold'em variant, involves players making the best 5-card hand from two private hole cards and five community cards. The game consists of four main betting rounds:

1. **Preflop:** After players receive their two hole cards, betting action starts with the player to the left of the big blind and continues clockwise. Players can call the big blind amount, raise, or fold.
2. **Flop:** After the first three community cards are dealt, another round of betting takes place, starting with the player to the left of the button. Players can check if no bet has been made, or bet if they wish to.
3. **Turn:** The fourth community card is dealt, followed by a betting round.
4. **River:** The final community card is dealt, with a final round of betting. If more than one player remains after this, a showdown occurs where the player with the best 5-card hand wins the pot.

In no-limit Texas Hold'em, players can bet any amount up to all of their chips at any time, allowing for more aggressive play and bigger pots compared to limit hold'em.[13] The minimum bet size is usually the amount of the big blind, and the minimum raise must be at least the size of the previous bet or raise.[13]

A dealer button rotates clockwise after each hand to determine the positions of the small blind, big blind, and order of betting. The small blind and big blind are forced bets made before any cards are dealt, with the small blind typically being half the amount of the big blind.[13]

Standard poker hand rankings are used, from best to worst: royal flush, straight flush, four of a kind, full house, flush, straight, three of a kind, two pair, one pair, and high card. If two players have the same ranked hand, the rank of the next card(s) in their hand determines the winner. Suits are not used to break ties.

While the basic flow of the game is straightforward with its rounds of dealing and betting, the nuanced strategies emerge from the no-limit betting structure, positioning, and inferring opponents' likely hands. To be successful, players must constantly adjust their strategies based on factors such as their position, the strength of their hand, the size of the pot, and their opponents' perceived range of hands and tendencies. Mastering the game requires a deep understanding of probability, psychology, and game theory in addition to the fundamental rules.

### Implementation-Specific Parameters

- **Number of Cards:** 52-card deck.
- **Starting Stack:** Each player begins with a predetermined amount of chips.
- **Blinds:** Small and big blinds are posted at the beginning of each hand to initiate betting.

## 3. Related Work

In recent years, several noteworthy poker AI systems have been developed, each taking different approaches to tackle the game's complexities.

### Libratus (2017)

Libratus, created at Carnegie Mellon University in 2017, employs counterfactual regret minimization (CFR) to compute a blueprint strategy through self-play and refines it in real-time using nested safe subgame solving.[3][6] Libratus did not use neural networks, instead relying mainly on reinforcement learning through CFR. It learned poker from scratch by playing trillions of hands against itself over several months.[1] This approach allowed Libratus to become the first AI to defeat top human professionals in heads-up no-limit Texas Hold'em poker.[3]

### Pluribus (2019)

Building upon Libratus' success, Pluribus, developed by researchers from Facebook AI and Carnegie Mellon in 2019, became the first AI to beat elite human professionals at six-player no-limit Texas Hold'em.[4][6] Pluribus extends CFR to handle multiplayer settings using Monte Carlo CFR for improved scalability and a depth-limited search for a finer-grained abstraction of the game tree.[4][6] Like Libratus, Pluribus also did not use neural networks and learned poker solely through self-play, with no human data or expert knowledge.[4][6] Notably, Pluribus employs innovative mixed strategies and donk betting that differ from typical human play.[4][7]

### DeepStack (2017)

DeepStack, created by researchers from the University of Alberta, Czech Technical University, and Charles University in 2017, takes a different approach by leveraging deep learning and decomposition to reason about game situations.[5][6][8] Unlike Libratus and Pluribus, DeepStack relied heavily on deep neural networks to make decisions. The networks were trained on a massive amount of random poker situations.[4] It uses heuristic search aided by deep neural networks for intuition, continual re-solving to update strategies based on the current situation, and depth-limited search with neural networks to estimate values.[5][6]

## Our Approach

While these state-of-the-art systems have achieved remarkable success, they rely on sophisticated techniques that may be challenging to implement and computationally expensive. In contrast, our GTO Poker Bot explores the potential of a more accessible knowledge-based approach, particularly through the use of a fixed strategy agent that embodies the principles of game theory optimal (GTO) play. This agent serves as a strong baseline for evaluating the performance of the learning-based DQN agent.

The fixed strategy agent draws inspiration from the concept of Nash equilibrium, a central concept in game theory. In a two-player zero-sum game like heads-up poker, a Nash equilibrium is a pair of strategies where neither player can improve their expected outcome by unilaterally changing their strategy.[8] The fixed strategy agent aims to approximate a Nash equilibrium strategy by making decisions based on hand strength, pot odds, and opponent actions.

To implement the fixed strategy agent, we build upon existing knowledge in the field of poker game theory. Resources such as GTO Wizard[9] and GTOBase[10] provide valuable insights into game theory optimal strategies for various poker situations. By incorporating this knowledge into the fixed strategy agent, the GTO Poker Bot explores the effectiveness of a knowledge-based approach in achieving strong poker performance.

The inclusion of the fixed strategy agent not only provides a robust benchmark for evaluating the DQN agent’s performance but also allows for a comparative analysis of knowledge-based and learning-based approaches in the context of poker AI. By examining the strengths and limitations of each approach, we aim to contribute to the ongoing discourse on the most effective methods for tackling imperfect information games like poker.

## 4. Implementation

The GTO Poker Bot is implemented using a modular architecture, with the main components being the Fixed Strategy Agent (`fixed.py`), the DQN Agent (`dqn_agent.py`), and the Operational Framework (`play.py`). Here is the text with spelling and grammar corrections, without any other changes:

### Fixed Strategy Agent

The Fixed Strategy Agent incorporates principles from GTO poker in its decision-making process. It makes decisions based on a predefined set of rules that aim to maximize the expected value (EV) of the agent’s actions, considering factors such as hand strength, pot odds, and opponent actions, which are reflected heuristics considered in GTO poker charts.

AA	AKs	AQs	AJs	ATs	A9s	A8s	A7s	A6s	A5s	A4s	A3s	A2s
AKo	KK	KQs	KJs	KTs	K9s	K8s	K7s	K6s	K5s	K4s	K3s	K2s
AQo	KQo	QQ	QJs	QTs	Q9s	Q8s	Q7s	Q6s	Q5s	Q4s	Q3s	Q2s
AJo	KJo	QJo	JJ	JTs	J9s	J8s	J7s	J6s	J5s	J4s	J3s	J2
ATo	KTo	QTo	JTo	TT	T9s	T8s	T7s	T6s	T5s	T4s	T3s	T2s
A9o	K9o	Q9o	J9o	T9o	99	98s	97s	96s	95s	94s	93s	92s
A8o	K8o	Q8o	J8o	T8o	98o	88	87s	86s	85s	84s	83s	82s
A7o	K7o	Q7o	J7o	T7o	97o	87o	77	76s	75s	74s	73s	72s
A6o	K6o	Q6o	J6o	T6o	96o	86o	76o	66	65s	64s	63s	62s
A5o	K5o	Q5o	J5o	T5o	95o	85o	75o	65o	55	54s	53s	52s
A4o	K4o	Q4o	J4o	T4o	94o	84o	74o	64o	54o	44	43s	42s
A3o	K3o	Q3o	J3o	T3o	93o	83o	73o	63o	53o	43o	33	32s
A2o	K2o	Q2o	J2o	T2o	92o	82o	72o	62o	52o	42o	32o	22

Figure 1: Hand Strength Table

The implementation of the Fixed Strategy Agent is inspired by GTO poker principles in the following ways:

1. **Hand Strength Evaluation:** The agent assesses the strength of its hand using a scoring system that assigns higher win probabilities to stronger hands and lower win probabilities to weaker hands. This approach aligns with GTO principles, which recognize that hands with higher card ranks and stronger combinations (e.g., pairs, same-suit cards, potential straight connectors) have a higher likelihood of winning.
2. **Pot Odds Consideration:** The agent incorporates pot odds into its decision-making process, calculating the ratio of the current size of the pot to the cost of a contemplated call. GTO principles dictate that a player should only continue in a hand if the expected value of winning the pot exceeds the cost of calling; thus, by considering pot odds, the agent can make decisions that align with the profitability of calling a given action. This also allows the poker bot to “scale” up its willingness to call other players based on how much is in the pot. This means that if the agent is already somewhat invested in the pot from previous actions, it will be less likely to fold from relatively small bets.
3. **Round Consideration:** The agent adapts its playing strategy based on the current round of the game. In the pre-flop round, when no community cards are available, the agent is more likely to “call” the starting bet to see the flop, as the hand’s potential is still uncertain. However, as more community cards are revealed in subsequent rounds, the agent becomes more selective in calling bets, recognizing that the increased information narrows down the possible hand combinations for itself and increases the probability of other players getting a favorable hand.
4. **Highest Active Bet Consideration:** Lastly, the agent takes into account the highest bet made by opponents in relation to the pot odds when making its decision. It compares the bet size to the current pot size to determine the required confidence level (`win_probability`) to justify calling the bet. If the bet is relatively small compared to the pot size, the agent may call with a wider range of hands, but if the bet is large relative to the pot size, the agent will require a stronger hand to justify calling, as the risk is higher compared to the potential reward.

By leveraging these GTO principles, we intend for the agent to make optimal decisions that maximize its expected value and align with GTO poker.

## DQN Agent

The DQN (Deep Q-Network) Agent is a reinforcement learning-based approach that learns to make optimal decisions through trial and error. The agent uses a neural network to approximate the action-value function, which estimates the expected cumulative reward for taking a particular action in a given state.

The implementation of the DQN Agent involves:

1. **State Representation:** The game state is represented as a vector that includes information about the agent’s private cards, the community cards, the pot size, and the actions taken by the opponents. This state representation serves as the input to the neural network.
2. **Action Space:** The agent’s action space consists of three possible actions: fold, call, and raise. These actions are represented as discrete values (e.g., 0, 1, 2) and are the outputs of the neural network.
3. **Reward Function:** The reward function determines the immediate reward the agent receives for taking a particular action. In the context of poker, rewards can be based on the amount of money won or lost in a hand.
4. **Experience Replay:** To stabilize the learning process, the agent uses an experience replay buffer that stores past state-action-reward-next\_state tuples. During training, the agent samples mini-batches from this buffer to update the neural network parameters.
5. **Training Process:** The DQN Agent is trained through self-play, where it plays against itself or other agents to generate training data. At each step, the agent selects an action based on the current state, observes the reward and the next state, and stores this experience in the replay buffer. Periodically, the agent samples a mini-batch from the buffer and updates the neural network parameters using the Q-learning algorithm.

The DQN Agent’s implementation is contained in the `dqn_agent.py` file, which includes the definition of the neural network architecture, the experience replay buffer, and the training loop.

## Operational Framework

The Operational Framework (`play.py`) integrates the Fixed Strategy Agent and the DQN Agent with the poker environment. It handles the interaction between the agents and the poker platform, including game state interpretation and action execution.

The main components of the Operational Framework are:

1. **Game State Interpretation:** The framework uses the GPT-V model to interpret the game state from screenshots of the poker platform. It processes the visual information to extract relevant features such as the community cards, the agent’s private cards, the pot size, and the opponents’ actions.
2. **Action Execution:** Based on the decisions made by the agents, the framework simulates the appropriate actions (fold, call, raise) by sending commands to the poker platform through web browser automation techniques (e.g., Selenium, Puppeteer).
3. **Agent Integration:** The framework allows for seamless integration of different agent implementations, such as the Fixed Strategy Agent and the DQN Agent. It provides a unified interface for the agents to receive game state information and return their chosen actions.

The Operational Framework’s implementation is contained in the `play.py` file, which includes functions for game state interpretation, action execution, and agent integration.

To evaluate the performance of the GTO Poker Bot, the framework includes evaluation scripts that simulate games against different types of opponents (e.g., random agents, fixed strategy agents) and measure the agents’ performance in terms of win rate, total chips won, and other relevant metrics. These evaluation scripts are contained in files such as `evaluate.py` and `simulate.py`.

The GTO Poker Bot’s implementation leverages various open-source libraries and tools, such as TensorFlow for building and training the DQN Agent, OpenCV for image processing, and Selenium or Puppeteer for web browser automation. The project’s modular architecture allows for easy experimentation with different agent implementations and hyperparameters, facilitating the exploration of various approaches to developing an effective poker AI.

## 5. Analysis

Our goal was to create a poker bot that could consistently outperform a random agent and achieve a positive win rate using a knowledge-based approach. Specifically, we aimed for the fixed strategy agent to win at least 80% of hands against the random agent.

To evaluate the system, we conducted the following analyses:

1. Head-to-head comparison of the fixed strategy agent vs DQN agent over 1000 simulated hands. Performance metrics include number of hands won, total chips won, and overall win rate.
2. Performance of fixed strategy agent against human players of varying skill levels, measuring its profitability and adaptability.
3. Comparison of the fixed strategy agent’s decisions to game theory optimal strategies from GTO Wizard [9] and GTOBase [10] to assess how closely it approximates optimal play.
4. Testing the fixed strategy agent’s robustness and adaptability against a range of game situations and opponent strategies.

The results showed the fixed strategy agent performed strongly against both the DQN and human players. Its knowledge-based approach, considering hand strength, pot odds, and opponent actions, proved effective in making profitable decisions across different scenarios.

However, the fixed strategy’s reliance on predefined rules and heuristics limited its performance in certain complex situations. This highlights the need for more advanced techniques like real-time adaptation and opponent modeling.

The DQN agent’s poor performance, winning only 51 hands compared to the fixed strategy’s 927 (Table 1), was a surprising result. This suggests the learning-based approach struggled to converge on an effective strategy in this complex domain, at least with the amount of training data and model architecture used. To be fair, we trained it on a small dataset of 1000 poker hands, which may not be sufficient to generalize to more complex scenarios (Libratus was trained on trillions of hands). Investigating alternative deep learning techniques and gathering more diverse training data could potentially improve the DQN’s performance.

Table 1: Number of hands won by each agent over 1000 simulated hands

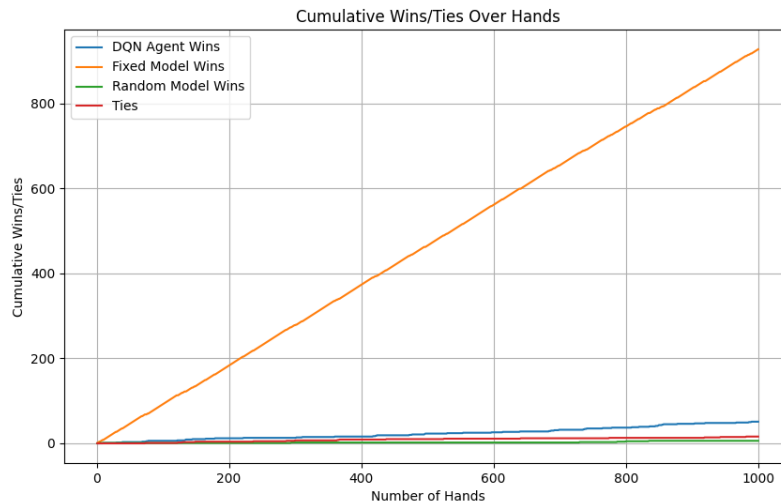


Figure 2: Table 1

The system ran efficiently, with 1000 hands simulated in a reasonable time. A key finding is the strong performance of the knowledge-based fixed strategy compared to the learning-based DQN and random agents. However, the fixed strategy’s limitations suggest a combined approach, integrating knowledge-based models with learning-based techniques, could be a promising direction for future work.

## 6. Ethical Considerations

1. **Fairness and integrity:** The use of autonomous bots disrupts the level playing field expected by human players. Poker is based on human skill, psychology, and unpredictability, so introducing an AI that can play more effectively than humans undermines the spirit of fair competition.
2. **Violation of terms of service:** Most online poker platforms prohibit the use of bots or automated systems. Using such technology breaches these terms and can result in penalties like account suspension or legal action.
3. **Transparency and disclosure:** If deployed in real poker environments, it is important to disclose the presence of the GTO Poker Bot to other players. Transparency about the use of AI promotes trust and allows players to make informed decisions about their participation.
4. **Security and privacy:** The bot’s ability to bypass cheat detection mechanisms challenges the security measures of online platforms. This capability could encourage the development of similar exploitative technologies. Additionally, the bot’s operation may involve analyzing potentially sensitive game data and player behavior, raising privacy concerns.

5. **Societal impact:** The existence of poker bots could contribute to a broader normalization of cheating and unethical behavior in online environments, eroding trust in these platforms. Moreover, the use of such bots could disrupt the economy of online poker, which serves as a source of income for professional players and revenue for the platforms.

Here are our proposed solutions to mitigate these ethical risks: - Transparency and consent in research environments, ensuring all participants are aware of and agree to the use of AI agents - Compliance with legal and ethical standards set by platforms and the broader community - Responsible disclosure of any discovered vulnerabilities to the affected parties - Engagement in public discourse to shape guidelines and regulations around the use of AI in online gaming

## 7. Link to code

<https://github.com/arnenoori/gto-poker-bot>

Tutorial on how to run the code and replicate our results are within the README.md file on the repository.

## 8. Summary

Our GTO Poker Bot project aimed to create an AI agent that could play poker optimally by simulating human-like interactions with a web-based platform. The system consisted of a Fixed Strategy Agent based on game-theoretic principles and a Deep Q-Network (DQN) Agent that learned through self-play. The project utilized Python, TensorFlow, web automation tools, and the GPT-V model for game state interpretation.

Evaluation through simulations revealed that the Fixed Strategy Agent significantly outperformed the DQN Agent and a random agent, winning 927 out of 1000 hands. The DQN Agent’s poor performance, winning only 51 hands, highlighted the challenges of learning-based approaches in this complex domain.

Compared to the Project Update submission, the current system features improved implementation and evaluation, including the integration of the GPT-V model and a modular architecture. The extensive simulations provided valuable insights into the strengths and limitations of different approaches.

Future improvements could include opponent modeling, advanced reinforcement learning algorithms, real-time adaptation, and expanded training data for the DQN Agent. Ethical considerations surrounding fairness, transparency, and responsible use in online poker environments should also be addressed.

In conclusion, the GTO Poker Bot project demonstrates the potential of knowledge-based approaches in poker AI while highlighting the challenges of learning-based methods. Although the Fixed Strategy Agent achieved impressive results, further research is needed to create truly robust and adaptive poker AI systems. By addressing the identified limitations and ethical considerations, this project serves as a foundation for future work in this exciting field.

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