



OSTBAYERISCHE
TECHNISCHE HOCHSCHULE
REGENSBURG

INFORMATIK UND
MATHEMATIK

Neural Networks vs. GRU in League of Legends Match Outcome Prediction: A Data-Centric Perspective

Bachelorarbeit
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Abgabedatum: 13. Dezember 2023

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1 Introduction

esports is highly relevant due to it being a huge and strongly growing market. In 2019, the esports industry's market size was valued at approximately 25B USD [1]. Esports and mobas in particular are hard to understand and follow. A live game prediction view can help fans understand the action and decisions made better and help immerse the audience by detecting upsets and swings in win probability. many games are hard to understand, due to lots of information being displayed with very little explanation a win prediction graph can help viewers understand the action and the significance of certain plays better, thus increasing engagement and enjoyment. riot games has already implemented their own proprietary win prediction a win prediction model can also help players make more informed decisions about what the optimal path of actions is

the model should be able to answer the question, if team a is far enough ahead to win or if team b with their hyperscaling heroes can come back and win

2 Related work

Utilizing machine learning methods to extract information from data generated by e-sport games is an area of ongoing research. A lot of scientific research focuses on the similar Multiplayer Online Battle Arena (MOBA) DotA 2, which has easier and more fine-grained data collection methods (see section 4.1). Due to the high similarity between these two games, it is to be expected that any findings for one game can be replicated and used for the other game with minimal adaptations. Nevertheless, to ensure a fair comparison, both games are presented separately below.

In DotA 2, a wide variety of algorithms have been used. Yu et al. [2] trained a Recurrent Neural Network (RNN) on 71,355 matches and achieved an accuracy of 0.7083 at the half-way point of a match, which according to their analysis is on average at 20 minutes. Wang [3] compared Logistic Regression with a Feedforward Neural Network (FNN) trained on up to 911,468 matches, with Logistic Regression (LR) achieving a slightly better accuracy (0.6104) than the FNN (0.588).

Silva et al. have used RNNs to predicting the winner using data of different time intervals. They achieved an accuracy of 75% when using data from between the 10 and 15 minute mark. An evaluation of LSTM resulted in lower accuracy, most likely due to the large amount of data required [4].

3 Background

3.1 League of Legends

League of Legends (LoL), developed by Riot Games, is a prominent MOBA game, a subgenre of real-time strategy games characterized by two teams of five players, known as 'summoners', competing against each other [5]. Each player controls a unique character, or 'champion', and the objective is to defeat the opposing team. LoL stands out in the MOBA genre for its global popularity, attracting millions of players and a significant viewership in professional esports tournaments [6].

While sharing core gameplay elements and map layouts with other MOBA games, LoL distinguishes itself through its diverse range of champions, abilities, and graphical styles. This thesis will therefore focus on League of Legends, given its influential status in the MOBA genre. The game's map is bifurcated into two bases, each linked by three lanes and housing a crucial structure called the 'nexus', which is protected by turrets. The game's primary goal is to destroy the opposing team's nexus. The map includes a jungle area in between the lanes with neutral monsters and two significant creatures, Baron Nashor and the Dragon, offering team-wide benefits when defeated. Players must accumulate gold and experience points (xp) through defeating minions, neutral monsters, or enemy champions. These in-game currencies are essential for purchasing items and leveling up, thereby augmenting a champion's capabilities.

Player roles in LoL are typically assigned with one player in the top lane, one in the mid lane, two in the bottom lane, and one in the jungle, facilitating strategic diversity and role specialization. Players select from a roster of 165 champions, each with unique abilities and characteristics, to compete in matches. Champion selection is a pivotal element of LoL gameplay, requiring players to consider team composition, damage types, assigned roles, and personal proficiency with specific champions. The theoretical number of possible champion combinations in a game is $\binom{165}{10} = \frac{165!}{10! \cdot (165-10)!}$, underscoring the game's strategic depth.

Each year, LoL introduces a new 'season', bringing substantial changes, and Riot Games issues bi-weekly patches to adjust champion balance, influencing the prevailing game strategies, or 'meta'. These patches can also include the release of a new champion or the rework of an old one. Frequent changes force players to be able to quickly adapt and learn new champions and mechanics.

To evaluate player skill, LoL utilizes a proprietary rating system, probably a modified Elo system [7]. This system ensures that players are matched with and against others of comparable skill levels, maintaining competitive balance and fairness in the game.

3.2 Neural Networks

Artificial Neural Networks (ANNs) are computational models that emulate the processing patterns of the human brain. The fundamental computational unit of an ANN is the neuron, a concept first proposed by McCulloch et al. [8]. A neuron computes an output activation a from a set of input values $\mathbf{x} = (x_1, x_2, \dots, x_m)$, where m denotes the number of inputs. The neuron's weighted input z is calculated as the dot product of the input vector \mathbf{x} and the weight vector $\mathbf{w} = (w_1, w_2, \dots, w_m)$, plus a bias term b :

$$z = \sum_{i=1}^m w_i x_i + b = \mathbf{w}^\top \mathbf{x} + b. \quad (1)$$

The weighted sum z is then passed through an activation function ϕ , such as a sigmoid or Rectified Linear Unit (ReLU), to introduce non-linearity:

$$a = \phi(z) = \phi(\mathbf{w}^\top \mathbf{x} + b). \quad (2)$$

The Multi-Layer Perceptron (MLP), introduced by Rosenblatt [9], organizes neurons into layers. Data flows from the input layer, through one or more hidden layers, to the output layer. In a fully connected feed-forward network, the computation in each layer l is:

$$\mathbf{a}^{(l)} = \phi(\mathbf{W}^{(l)} \mathbf{a}^{(l-1)} + \mathbf{b}^{(l)}), \quad (3)$$

where $\mathbf{a}^{(l)}$ represents the activation of layer l , $\mathbf{W}^{(l)}$ is the weight matrix, and $\mathbf{b}^{(l)}$ the bias vector. The output layer L produces the network's prediction \hat{y} .

To approximate any measurable function, an ANN requires at least one hidden layer [10]. The network's weights and biases are adjusted during training to minimize a loss function E . Common loss functions include Mean Squared Error (MSE) for regression tasks:

$$E_N = \frac{1}{N} \sum_{k=1}^N (y_k - \hat{y}_k)^2, \quad (4)$$

and Cross-Entropy Loss (CEL) for binary classification tasks:

$$E_N = -\frac{1}{N} \sum_{k=1}^N (y_k \ln \hat{y}_k + (1 - y_k) \ln (1 - \hat{y}_k)), \quad (5)$$

where N is the number of samples, y_k is the true label, and \hat{y}_k is the predicted value.

Backpropagation is a key algorithm for training ANNs, involving a forward pass to compute activations and a backward pass to compute gradients. The gradients of the loss function with respect to the weights and biases are computed using the chain rule of calculus. For a given layer l , the gradient of the loss E with respect to the weights $\mathbf{W}^{(l)}$ is:

$$\frac{\partial E}{\partial \mathbf{W}^{(l)}} = \frac{\partial E}{\partial \mathbf{a}^{(l)}} \cdot \frac{\partial \mathbf{a}^{(l)}}{\partial \mathbf{z}^{(l)}} \cdot \frac{\partial \mathbf{z}^{(l)}}{\partial \mathbf{W}^{(l)}}, \quad (6)$$

where $\mathbf{z}^{(l)} = \mathbf{W}^{(l)} \mathbf{a}^{(l-1)} + \mathbf{b}^{(l)}$ and $\mathbf{a}^{(l)} = \phi(\mathbf{z}^{(l)})$. The gradients are then used to update the weights and biases, typically using an optimization algorithm like gradient descent.

Through iterative forward and backward propagation, the network gradually converges to a state where the loss is minimized, indicating successful learning of the patterns in the data.

3.3 Recurrent Neural Networks

Recurrent Neural Networks (RNNs) extend the capabilities of feed-forward neural networks to handle sequential data by introducing the concept of recurrence. In an RNN, the output at each time step is influenced not only by the current input but also by the network's previous internal state, known as the hidden state. This design enables RNNs to capture temporal dependencies, making them particularly effective for tasks involving sequential data, such as speech recognition and natural language processing [11]. The concept of a fully connected RNN was first proposed by Elman [12]. RNNs maintain a 'state vector' in their hidden units, which implicitly contains information extracted from all past elements of the sequence [11]. The output \hat{y}_t of an RNN at time step t can be calculated as:

$$\hat{y}_t = \sigma(Vh_t + b_o), \quad (7)$$

where V is the weight matrix and b_o the bias vector associated with the cell output. The hidden state h_t at time step t is updated as follows:

$$h_t = \begin{cases} 0, & \text{if } t = 0, \\ \sigma(Wx_t + Uh_{t-1} + b_h), & \text{otherwise,} \end{cases} \quad (8)$$

where σ is the sigmoid activation function, U and b_h are the weight matrix and bias vector for the hidden state, and W is the weight matrix for the input. In a single-layer RNN, one hidden weight matrix W_h is shared across all timesteps.

Backpropagation Through Time (BPTT) unfolds the RNN across time steps (see figure 1) and applies the backpropagation algorithm. The gradients of the loss function with respect to the weights are calculated for each time step. For a given time step t , the gradient of the loss E with respect to the weights W is:

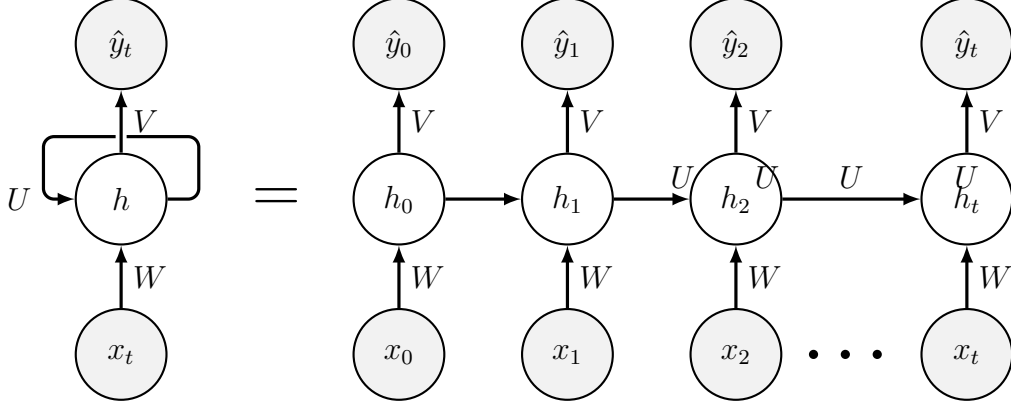
$$\frac{\partial E}{\partial W} = \sum_{\tau=1}^t \frac{\partial E}{\partial \hat{y}_\tau} \cdot \frac{\partial \hat{y}_\tau}{\partial h_\tau} \cdot \frac{\partial h_\tau}{\partial W}, \quad (9)$$

where $\frac{\partial E}{\partial \hat{y}_\tau}$ is the gradient of the loss with respect to the output at time τ , $\frac{\partial \hat{y}_\tau}{\partial h_\tau}$ is the gradient of the output with respect to the hidden state, and $\frac{\partial h_\tau}{\partial W}$ is the gradient of the hidden state with respect to the weights. This process is repeated for all weights and biases in the network, allowing the RNN to learn from sequences by adjusting its parameters based on the temporal context.

However, as demonstrated by Bengio et al. [13], RNNs face challenges with exploding or vanishing gradients, particularly in long sequences. This issue hinders their ability to learn long-range dependencies [14].

3.4 GRU

In order to overcome the exploding/vanishing gradient problem of vanilla RNNs, gated networks like the Long Short-Term Memory (LSTM) [15] and Gated Recurrent Unit

**Figure 1:** Unrolling of a RNN over time

(GRU) [16] have been developed [17]. As they introduce an increased number of parameters compared to traditional RNNs, gated networks like the LSTM and GRU demand greater computational power [18]. Compared to the LSTM network, GRU reduces the number of gate networks to two, thus being simpler to implement and compute [16]. Chung et al. even found that GRU is at least comparable to LSTM most of the time [19]. The gates control the activation of each hidden unit. The reset gate is calculated by

$$r_t = \sigma(W_r x_t + U_r h_{t-1} + b_r) \quad (10)$$

and the update gate z_j by

$$z_t = \sigma(W_z x_t + U_z h_{t-1} + b_z) \quad (11)$$

[18]. The hidden state update is a linear interpolation between the previous activation h_{t-1} and the candidate activation \tilde{h}_t , where the update gate z_t influences how much the hidden state is changed [19]:

$$h_t = (1 - z_t) \odot h_{t-1} + z_t \odot \tilde{h}_t \quad (12)$$

with

$$\tilde{h}_t = g(W_h x_t + U_h (r_t \odot h_{t-1} + b_h)) \quad (13)$$

. In equations 12 and 13 \odot denotes the elementwise (Hadamard) multiplication and the function g in equation 13 is the activation function.

3.5 Feature Selection Algorithms

Feature selection in neural network modeling is crucial, especially when dealing with high-dimensional data. It primarily aims to enhance model performance by reducing the curse of dimensionality, which can improve predictive accuracy. Additionally, it helps in reducing overfitting, as irrelevant or redundant features are eliminated, thereby improving the model's ability to generalize. This process also contributes to the interpretability of the model, making it easier to understand the learned relationships. Furthermore, it can lead to reduced training times, as the network has fewer parameters to update during learning.

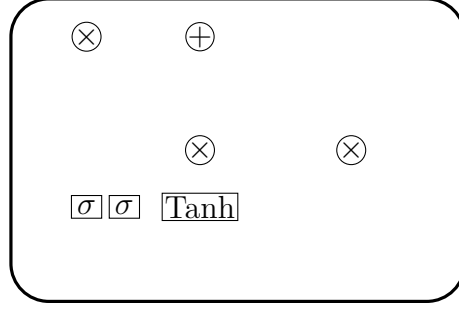


Figure 2: Gated Recurrent Unit

3.5.1 Pearsons' correlation coefficient

Pearsons correlation coefficient (PCC) is a statistical measure widely used to evaluate the linear relationship between two variables. Specifically, we consider its application in the context of feature selection in machine learning, where it is used to assess the linear correlation between input features and the target variable. We regard the input vector \mathbf{x} as a manifestation of an underlying, unknown distribution. Here, X_i represents the random variable corresponding to the i^{th} component of \mathbf{x} , and \mathbf{y} is the target value vector, viewed as a realization of the random variable Y [20]. PCC is employed to quantify the linear correlation between these two random variables. It is defined by the formula:

$$R(i) = \frac{\text{cov}(X_i, Y)}{\sqrt{\text{var}(X_i) \cdot \text{var}(Y)}}, \quad (14)$$

where $\text{cov}(X_i, Y)$ is the covariance between X_i and Y , and $\text{var}(X_i)$ and $\text{var}(Y)$ are the variances of X_i and Y , respectively [21]. In order to ascertain the significance of the test results, a hypothesis test needs to be performed, with the null hypothesis being that there is no correlation between the feature and the target. While simple and effective for identifying linear relationships, PCC only captures linear dependencies and might miss non-linear relationships crucial for neural networks.

3.5.2 Gradient Boosted Trees

Gradient Boosted Trees (GBT) is an ensemble learning technique that can be used for feature selection. It builds the model in a stage-wise fashion, with each tree being added to correct the errors made by the previous ones. There are different types of importance, such as the average or total gain across all splits the feature is used in. The simplest definition is the 'weight', defined as the number of times a feature is used to split the data across all trees [22].

4 Data

As two very different experiments are compared against each other, two different datasets need to be constructed: one dataset containing all relevant information prior to the start of the game and one dataset containing only the temporal information from the beginning of the game.

4.1 Data Collection

High-Rank Matches The focus of data acquisition was directed towards high-rank matches, in which a mix of excellent amateur and professional players play. Lower rank matches are not considered due to their higher unpredictability as less skilled players make huge, game-changing mistakes way more often. Pro matches, defined as professional players playing with their respective teams in an esports tournament or league, were not included as there are way less matches and they are not available through the official Riot Games API. High rank matches in this context are defined as having at least one player holding the rank of Master, Grandmaster or Challenger. Riot Games themselves considers any rank above Diamond 3 as 'Elite' [23], but we raise this bar just slightly to only include any rank above Diamond 1. Due to the fact that for a match to be included in the dataset, only one out of ten players needs to hold one of the aforementioned highest ranks, some slightly lower ranked players are also present in the dataset. These ranks combined account for the top 0.2% of all players [24].

Riot Games API The primary source of data stemmed from the Riot Games API, a comprehensive repository of information pertaining to League of Legends gameplay. The Riot Games API provided access to a plethora of essential data points, including champion statistics, general match information, timeline details, and player-specific information. These variables collectively form a comprehensive and multifaceted dataset crucial for the development of an effective predictive model.

Other Data Sources However, not all pertinent data were available directly from the Riot Games API. These include the winning chance of each champion and statistics on how each player performs on each relevant champion. To address this limitation, a web-scraping approach was employed to gather additional relevant information. The amalgamation of Riot Games API data and web-scraped data was meticulously organized and stored in a Database. This central repository served as the foundational storehouse from which distinct datasets were constructed, ensuring an organized and structured approach to data management.

Regions Multiple regions were included in the data collection process, including Europe West (EUW), Europe Nordic & East (EUN), Korea (KR), and North America (NA). This regional diversity contributes to the model’s generalizability across different player bases and playing styles.

Period of Time All matches included in the dataset were played in season 13 and on patch 20. It is important that all matches are played on the same patch, as a patch may cause major shifts in the balance of the game, thus making certain strategies and champions way better than others.

In summary, the data collection process for this study involved a dual-pronged approach, leveraging the extensive resources provided by the Riot Games API alongside a targeted web-scraping strategy. The resulting raw dataset containing 20,513 and 3,972 matches in the pre-game and in-game datasets respectively, stored in a PostgreSQL Database, reflects a comprehensive compilation of high-rank amateur League of Legends matches.

4.2 Dataset Properties

The matches collected have the following properties: As only matches with a game length of at least 16 minutes are collected, the shortest match is 16 minutes long, while the longest game is 59.62 minutes long. The average match length is 26.88 minutes.

4.3 Data Processing

4.3.1 Pre-Game Dataset

The raw pre-game dataset contains 368 columns which can be categorized into four distinct groups: General Match Information, Player Information, Champion Information and Player-Champion Information. General match details, such as the patch number, are exclusively utilized for validation purposes and are excluded from the final dataset.

Player Information Player Information feature x_p is a two-dimensional vector containing information about the player. This includes the account level, serving as an indicator of the player’s accumulated gaming experience, and the player’s rank, functioning as a metric for assessing the player’s skill level. transform rank info into a single float number winrate calculation

Champion Information The Champion Information feature \mathbf{x}_c is composed of

However, it is noteworthy that a limitation inherent in these metrics lies in their aggregation across all player ranks, reducing their specificity to the ranks under analysis. conversion of champion tier into integer

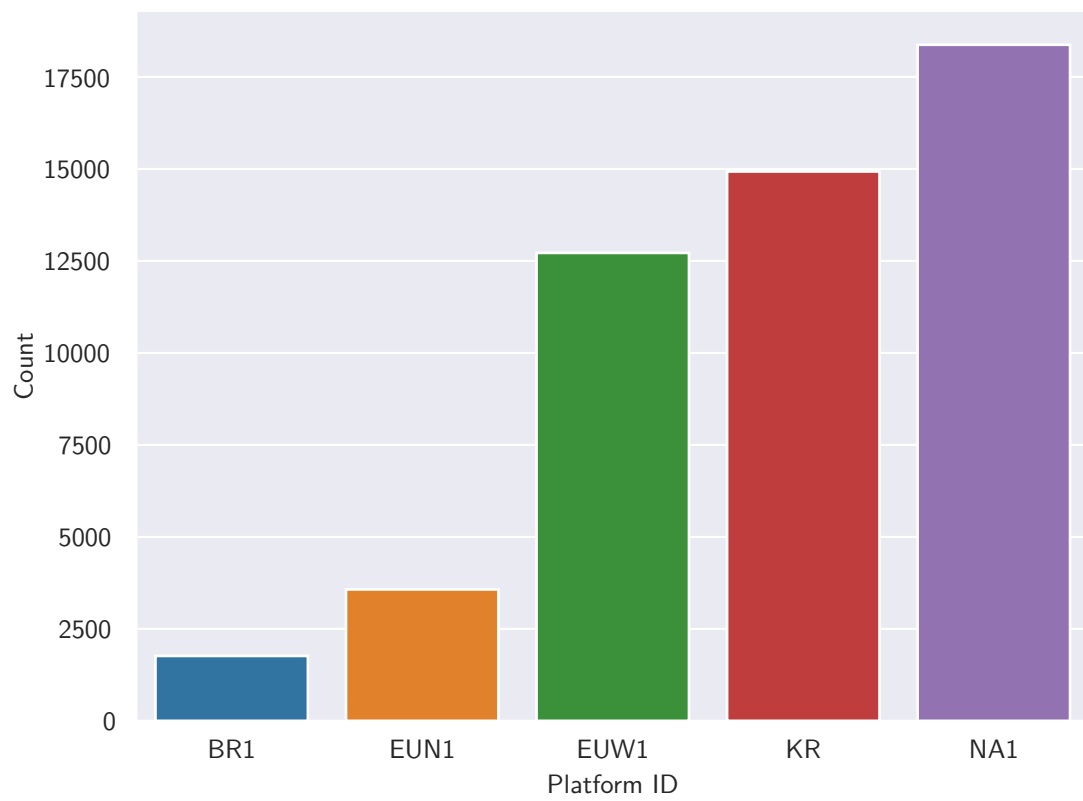


Figure 3: Region distribution of all matches in the dataset

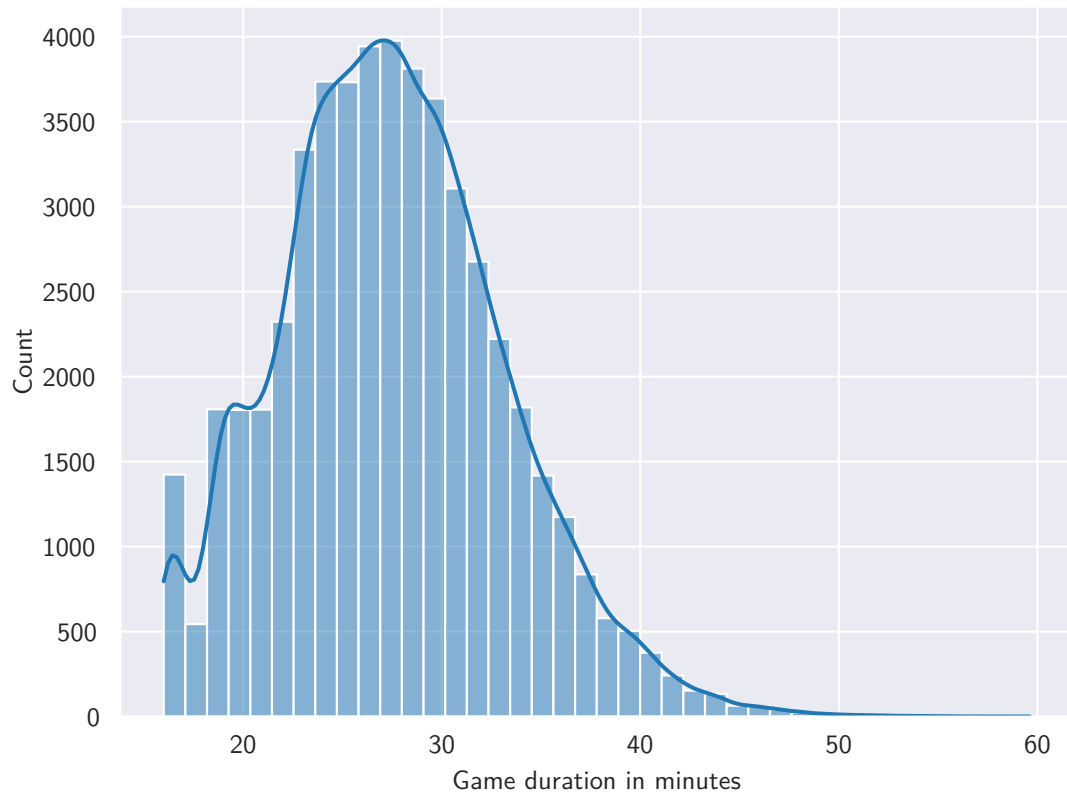


Figure 4: Distribution of game duration with its kernel density estimation. The spike at 16 minutes is explained by the fact that this is the earliest possible surrender time.

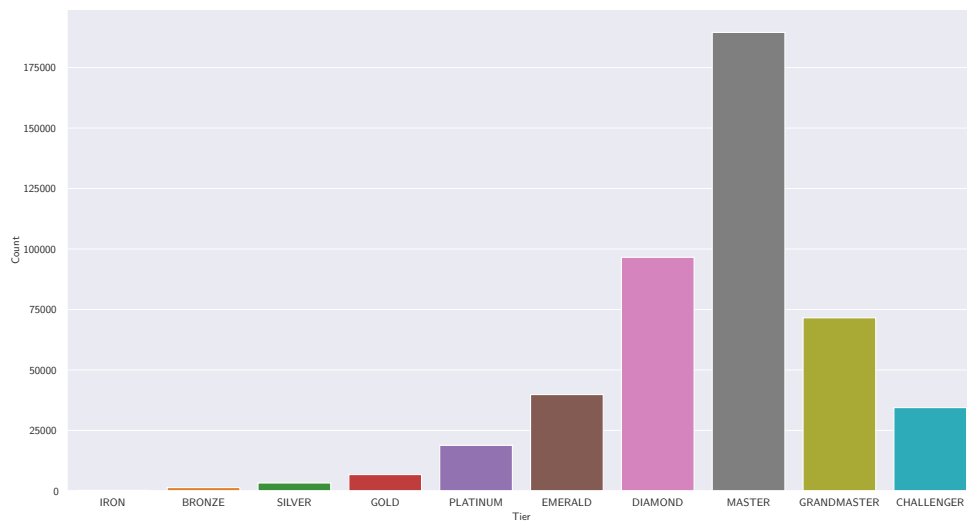


Figure 5: Distribution of ranks in the dataset

Player-Champion Information This feature vector contains information about the player on a specific champion. It encompasses metrics such as the average amount of gold earned by the player across all matches played on the champion during Season 13. Costa et al. [25] found that the most pivotal feature within this category is the player’s win rate while piloting this champion. Unfortunately, this information is not readily available to be extracted by our web scraper, necessitating its omission from the dataset. Each feature category like ‘average gold per match’ is split into 10 features, one for each participant. This is a very fine-grained approach, greatly increasing the dimensionality of the dataset. For some features, a broader approach is sufficient, where statistics are averaged for each team, reducing 10 features per category to two. champion number one hot encoded

Scaling and Partitioning In order to improve

4.3.2 In-Game Dataset

The raw in-game dataset contains 381 features describing the current state of the game after every minute. It primarily includes player-specific metrics such as damage dealt to opponents, champion level, and cumulative gold. These statistics, recorded per minute, create a discrete time series. Furthermore, key events like the number of turrets destroyed and each team’s total gold are tracked to more precisely gauge the game’s state. Gold, a critical indicator, underscores each victory milestone - be it destroying a turret or defeating an adversary. Often, the winning team can be predicted by analysing gold trends. As illustrated in Figure 6, members of the victorious team typically amass significantly more gold by the game’s conclusion compared to their counterparts.

Destroying turrets is crucial in the game, offering significant gold rewards and map control. With a minimum of five turrets required for victory, their destruction serves as a key indicator of a team’s likelihood to win.

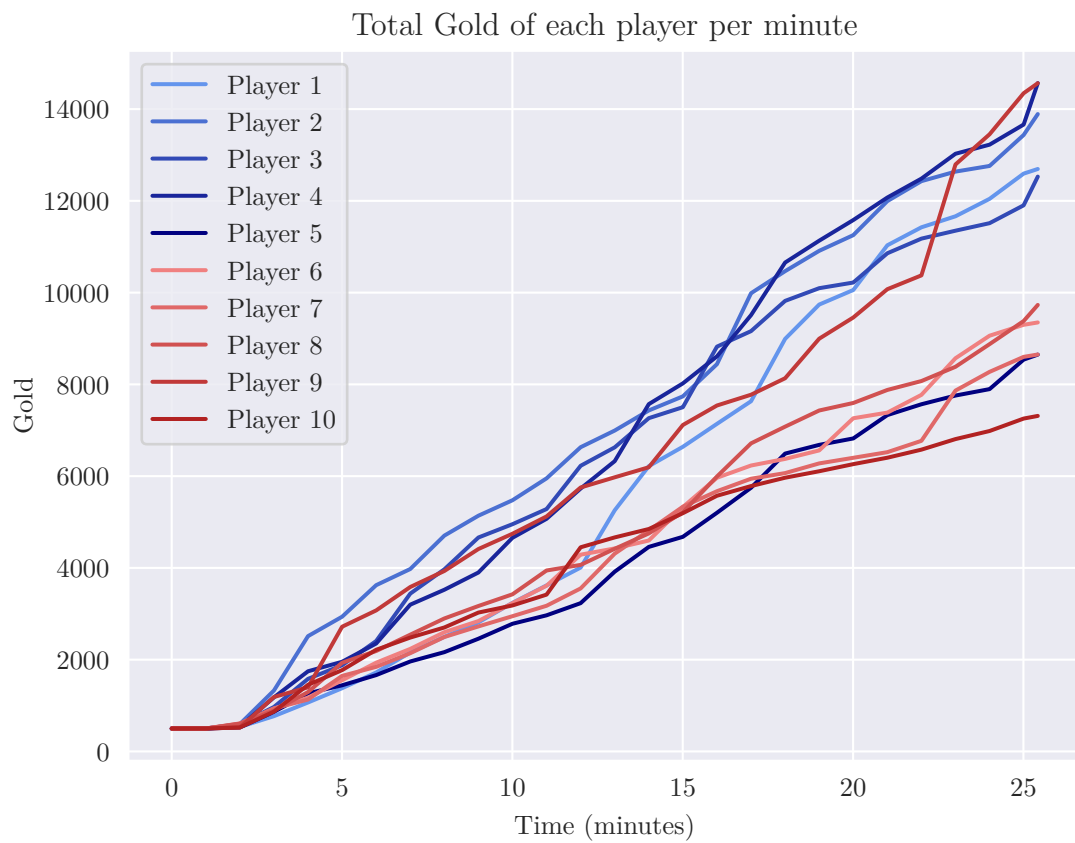


Figure 6: Total gold accumulated by each player of the course of the match, separated into teams by color. A clear separation between the blue and red team is noticeable especially at the later stages of the game.

5 Experiments

5.0.1 Feature Selection Results

As expected, the significance of the features does not differ much within a category, so the correlation coefficients are averaged per category. This enables a clearer result on the importance of feature categories.

The results of the test are found in table 1. All p -values in the table are below the significance threshold of 0.05, confirming the statistical significance of the correlation. The highest correlation is 0.15, belonging to the KDA feature. This feature measures the average ratio of $\frac{\text{kills} + \text{assists}}{\text{deaths}}$ the player achieved on his champion. This is a very low correlation, indicating that no single feature has a strong linear relationship with the target. This illustrates the need for multivariate analysis.

5.1 Pre-Game Classification

using neural network

5.1.1 Hyperparameter Optimization

5.2 Mid-Game Classification

Feature	Correlation coefficient	GBT Feature Importance
KDA	0.133	726
Deaths	0.092	284
Assists	0.081	403
Gold	0.063	393
Kills	0.060	310
LP	0.050	541
Champion Level	0.034	50
CS Per Minute	0.027	394
Last Play Time	0.026	349
Win Rate	0.022	301
Champion Tier	0.020	66
Champion Points	0.015	401

Table 1: Average Pearson’s correlation coefficient and average Gradient Boosted Tree Feature Importance for the 12 features categories with the highest absolute average correlation. Notably, the KDA feature is not only by far the most important, but its components Kills, Deaths and Assists are in the top 5 correlation coefficients as well.

6 Results

7 Discussion

8 Conclusion

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List of Abbreviations

ANN Artificial Neural Network

BPTT Backpropagation Through Time

CEL Cross-Entropy Loss

FNN Feedforward Neural Network

GBT Gradient Boosted Tree

GRU Gated Recurrent Unit

LoL League of Legends

LR Logistic Regression

LSTM Long Short-Term Memory

MLP Multi-Layer Perceptron

MOBA Multiplayer Online Battle Arena

MSE Mean Squared Error

NN Neural Network

NPC non-player character

PCC Pearsons correlation coefficient

ReLU Rectified Linear Unit

RNN Recurrent Neural Network

xp experience points