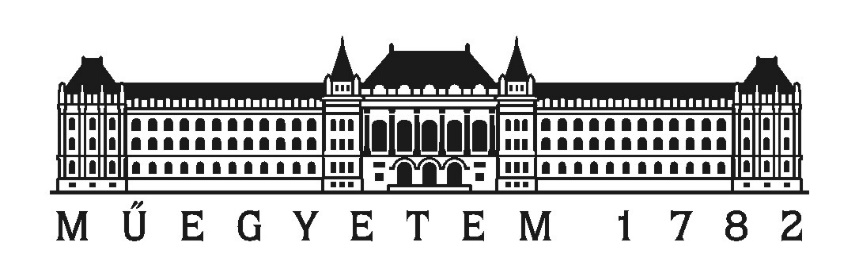
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Master Thesis

Tamas Bundy

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**Budapest University of Technology and Economics**

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Genetic algorithm-based hyperparameter optimization in credit risk analysis

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Abstract   
In this thesis we explore the application of genetic algorithms for hyperparameter optimization on the field of credit risk analysis. Hyperparameter optimization is crucial in machine learning to improve model performance and generalization. Traditional optimization techniques include exhaustive search or random search, which can be computationally expensive and impractical for ever evolving models. Genetic algorithms have an alternative approach learned from the process of natural selection and Darwinian evolution. Iteratively evolving a population of candidate solutions, genetic algorithms travers the hyperparameter space to find close to optimal configurations. Utilizing these optimized parameters our neural networks may find satisfactory results in credit risk datasets. Credit risk analysis is a demanding daily task in financial institutions for assessing the likelihood of default of borrowers. Industry practice usually relies on logistic regression models, that may not capture complex patterns in the datasets. In this thesis, we propose a modern approach that combines genetic algorithm (GA) for hyperparameter optimization and neural networks (NN) for modeling credit risk.

*Keywords: Genetic algorithms, Neural networks, Credit risk, AUC-ROC, PD*

List of abbreviations

1. API: Application Programming Interface
2. AUC-ROC: Area Under the Receiver Operating Characteristic Curve
3. CLI: Command Line Interface
4. CNN: Convolutional Neural Network
5. CPU: Central Processing Unit
6. CSV: Comma-Separated Values
7. CUDA: Compute Unified Device Architecture
8. DNN: Deep Neural Network
9. GA: Genetic Algorithm
10. GINI: Gini Coefficient
11. GPU: Graphics Processing Unit
12. IDE: Integrated Development Environment
13. JSON: JavaScript Object Notation
14. ML: Machine Learning
15. NN: Neural Network
16. PDF: Probability Density Function
17. PyTorch: Python-based scientific computing package for ML
18. ReLU: Rectified Linear Unit
19. RNN: Recurrent Neural Network
20. Sci-kit Learn: Python library for ML and data mining
21. SGD: Stochastic Gradient Descent

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GENETIC ALGORITHM-BASED HYPERPARAMETER OPTIMIZATION IN CREDIT RISK ANALYSIS

By Thomas Bundy

# Introduction

Credit risk analysis in financial institutions depend on the evaluation of borrowers' creditworthiness, a task to minimize potential losses from defaults. Traditional logistic regression models are widely used but may struggle to capture complex relationships in the data due to their linear nature. In this thesis, we propose a modern approach that combines Genetic Algorithm (GA) for hyperparameter optimization and Neural Networks (NN) for modeling credit risk. We attempt to demonstrate how this hybrid approach may improve the predictive performance compared to mentioned conventional methods.

Supervised learning algorithms, particularly NNs, have demonstrated potential in credit risk modeling because of their ability to handle nonlinear relationships and difficult patterns in data. However, the performance of NNs certainly depends on the right selection of hyperparameters. The hyperparameters among them are the learning rate, batch size, and network architecture significantly drive the model's effectiveness.

Genetic Algorithms present an efficient method for optimizing these hyperparameters, offering a solution to the challenge of manual tuning. According to a study by Nikolaev et al. (2002) published in the "Genetic Programming of Polynomial Models for Financial Forecasting", GAs have been successfully applied in various domains, including finance, for optimizing complex problems. They mimic the process of natural selection and evolution; GAs iteratively improves solutions to reach an optimal or close to optimal solution. In the context of NNs, GAs can efficiently explore the hyperparameter space to find configurations that could maximize the model performance.

To implement a GA for hyperparameter tuning for NNs several steps are needed. First, the hyperparameter space should be defined, specifying the range, or set of values for each parameter. This step determines the search space that the GA will explore. Second, an encoding scheme is required to represent potential solutions – these are the hyperparameter configurations – as chromosomes. Common encoding schemes include binary strings, real-valued vectors, or integer sequences.

Next, a fitness function is needed to be defined to be able to evaluate the performance of each solution. In our case of credit risk analysis, metrics like accuracy, precision, recall, and the area under the receiver operating characteristic curve (AUC-ROC) are commonly used to assess model performance. The fitness function can quantify how a concrete hyperparameter configuration helps the NN to accurately classify borrowers into two distinct categories, default, and non-default.

The GA step-by-step evolves a population of potential solutions through the actions of selection, crossover, and mutation operations. Selection involves choosing the fittest individuals – here, the hyperparameter configurations - from the current population to serve as parents for producing the next generation. The Crossover is combining genetic material from two parents to create offspring. Meanwhile Mutation introduces random changes to maintain genetic diversity within our population.

This process will not stop until a set termination criterion is met, for instance reaching a maximum number of generations or achieving a satisfactory model performance. Eventually, the best hyperparameter configuration discovered by the GA will be the one to train the NN on the entire dataset. Its performance is judged on a separate test set to assess its generalization ability.

This integration of GAs for hyperparameter tuning, could assist NNs to be fine-tuned to effectively capture the complexities of credit risk assessment and default discrimination. Leading to more accurate predictions and better risk management strategies for banks and other financial institutions.

# Literature review

Hyperparameter optimization is an important aspect of modern machine learning model development, aiming to upgrade model performances and generalization ability. Traditionally optimization methods, like exhaustive search or random search, are often computationally exhausting and impractical for complex models. GAs offer an alternative approach, inspired by the principles of natural selection and Darwinian evolution, to better explore the hyperparameter space and identify near-optimal configurations. In our context of credit risk analysis, where accurate prediction of default probabilities is economically important for financial institutions, the integration of GAs for hyperparameter optimization presents a promising future for improving efficacy.

## Genetic Algorithms in Machine Learning

Genetic algorithms have garnered significant attention in the field of machine learning due to their ability to effectively navigate high-dimensional search spaces and find optimal or near-optimal solutions. In a study by Goldberg (1989) titled "Genetic Algorithms in Search, Optimization, and Machine Learning," the author provides a comprehensive overview of genetic algorithms, detailing their mechanics and applications across various domains. By iteratively evolving a population of candidate solutions through selection, crossover, and mutation operations, genetic algorithms mimic the process of natural selection, gradually improving solutions over generations.

### Different Genetic algorithms

Genetic Algorithms (GAs) offering distinct approaches to navigate the search space and identify optimal configurations for machine learning models. Evolutionary strategies (ES), for instance, prioritize exploration by directly perturbing solutions based on their fitness, while Genetic Programming (GP) evolves symbolic representations of solutions, allowing for greater flexibility in problem-solving. Moreover, Differential Evolution (DE) employs differential mutation and crossover operators to iteratively improve candidate solutions. In our project focusing on credit risk analysis, we selected a standard Genetic Algorithm due to its balance between exploration and exploitation, making it suitable for navigating the complex hyperparameter space of neural networks. By maintaining diverse populations, employing crossover and mutation operations, and leveraging fitness-based selection mechanisms, our chosen GA efficiently explores the search space, facilitating the discovery of near-optimal hyperparameter configurations for enhancing the predictive performance of our neural network model.

The selection of GAs for hyperparameter optimization in our project is based on technical reasoning. Firstly, GAs are renowned for their global search capability (Holland), enabling efficient exploration of complex, high-dimensional search spaces. This capability is particularly crucial in the context of neural network hyperparameter optimization, where the interaction between numerous parameters can lead to intricate landscapes with multiple local optima. Moreover, GAs exhibit adaptability to nonlinear relationships (Michalewicz), a key characteristic of neural networks. By iteratively evolving a population of candidate solutions, GAs can dynamically adjust hyperparameters to capture complex patterns and relationships in the data, enhancing the model's predictive performance. Additionally, the robustness of GAs to local optima (Cantú-Paz) ensures that the optimization process does not prematurely converge to suboptimal solutions, thereby enabling the discovery of near-optimal configurations for credit risk modeling. Furthermore, the parallelization potential of GAs (Eiben) allows for efficient exploration of hyperparameter spaces, leveraging computational resources effectively and reducing optimization time. Finally, the stochastic nature of GAs (Eiben) introduces diversity into the search process, enabling exploration of novel solutions and adaptation to changing data patterns over time. These scientific and technical attributes make GAs a compelling choice for hyperparameter optimization in neural network-based credit risk modeling, contributing to the project's robustness and effectiveness.

## Genetic Algorithms for Hyperparameter Optimization

Hyperparameter optimization is a crucial step in machine learning model development, as the selection of appropriate hyperparameters significantly impacts model performance. Traditional methods such as grid search and random search are often inefficient and impractical for large hyperparameter spaces. GAs offer an alternative, as they can efficiently explore the hyperparameter space and identify configurations that might maximize a model’s performance.

In a study by Shahriari et al. (2016) titled "Taking the Human Out of the Loop: A Review of Bayesian Optimization," the authors discuss various optimization techniques, including genetic algorithms, for hyperparameter tuning in machine learning. The review highlights the effectiveness of genetic algorithms in finding optimal hyperparameter configurations, particularly in high-dimensional search spaces where traditional methods may struggle.

In the case of our thesis, the hyperparameter space is a three-dimensional discrete space. Each dimension corresponds to a different hyperparameter: learning rate, hidden layer sizes, and batch size. The discrete nature of the space comes from the fact that each of these hyperparameter can only take on a finite set of values from their respective ranges:

* Learning Rate: The rate at which the model weights of NNs are updated during training. It controls the step size in the optimization process. It is typically represented by a continuous range in [0.001, 0.01 0.1].
* Hidden Layer Sizes: The sizes of the hidden layers in the neural network architecture. These sizes determine the number of neurons in each hidden layer. For example, [128, 64, 32] represents three hidden layers with 128, 64, and 32 neurons respectively.
* Batch Size: The number of training examples utilized in one iteration of gradient descent during the backpropagation. It affects the speed and stability of the training process. Usually represented by a discrete range, such as [128, 64, 32].

All these combinations represent a point in the hyperparameter space that can be evaluated during optimization process. By traversing this set hyperparameter space that contains all possible combinations of learning rates, hidden layer sizes, and batch sizes within all their specified ranges; the process may find optimal values. The representation of the space mathematically, can be defined as Cartesian product of these ranges:

For instance, if we have a learning rate range of [0.001, 0.01 0.1], hidden layer sizes [128, 64, 32], and batch size options [128, 64, 32], the hyperparameter space would consist of all combinations of these values:

Where *lr* represents the learning rate, *hs* represents the hidden layer sizes, and *bs* represents the batch size. Each combination of *lr*, *hs*, and *bs* represents a point in the hyperparameter space that can be examined during optimization.

## Application of Genetic Algorithms in finance

The application of genetic algorithms in finance has been extensively explored, especially in portfolio optimization, trading strategy development, and modern credit risk analysis. In their study titled “A hybrid stock selection model using genetic algorithms and support vector regression” Huang et al. (2012) illustrate the effectiveness of integrating genetic algorithms and support vector machines in predicting stock market trends. The research underscores the utility of genetic algorithms in fine-tuning model parameters, resulting in enhanced predictive performance for financial forecasting endeavors. The study highlights the ability of genetic algorithms to optimize model parameters, leading to improved predictive accuracy in financial forecasting tasks.

### Genetic Algorithms in Credit Risk Analysis

Credit risk analysis plays a pivotal role in financial institutions' decision-making processes, aiming to assess the likelihood of default by borrowers. Traditional approaches to credit risk modeling often rely on logistic regression models, which may have limitations in capturing complex relationships in the data. In their paper titled "Credit Risk Assessment Using Genetic Algorithms Optimized Support Vector Machines," Behzadi et al. (2011) propose a novel approach that combines genetic algorithms with support vector machines for credit risk assessment. The study demonstrates the effectiveness of genetic algorithms in optimizing model parameters, leading to improved predictive accuracy in identifying credit default risks.

Integrating genetic algorithms into the model development process presents a promising avenue for improving risk management strategies and decision-making in financial institutions.

# Methodology

Our chosen methodology for this thesis work comprises two primary components. First, the hyperparameter optimization using genetic algorithms. Then a credit risk modeling process using neural networks. The integration of these two techniques aims to enhance the accuracy and robustness of credit risk assessment.

## Hyperparameter Optimization Using Genetic Algorithms

Genetic algorithms (GAs) are employed to efficiently search the hyperparameter space and identify the optimal configuration for the neural network model. This process involves the following steps:

1. Initialization: The GA begins by initializing a population of potential solutions, where each solution represents a unique hyperparameter configuration for the neural network. These configurations include parameters such as learning rate, batch size, number of hidden layers, and neuron activation functions.

2. Evaluation: Each solution in the population is evaluated based on its fitness, which is determined by the performance of the corresponding neural network model. Metrics such as accuracy, precision, recall, and AUC-ROC are used to assess the model's ability to classify borrowers into default and non-default categories. Our chosen fitness function is:

In our thesis project, the fitness function *f*(*x*) evaluates the performance of an individual *x* (hyperparameter configuration) based on its AUC-ROC score. A higher AUC-ROC score indicates better discrimination ability of the corresponding neural network model in identifying potential credit default risks.

3. Selection: The fittest individuals (hyperparameter configurations) from the current population are selected to serve as parents for producing the next generation. Selection is typically based on the individuals' fitness scores, with higher-scoring solutions being more likely to be chosen as parents.

Here, *P*(*x*) represents the probability of selecting individual *x* for reproduction, based on its AUC-ROC score relative to the total AUC-ROC scores of all individuals in the whole population.

4. Crossover: Crossover involves combining genetic material from two parent solutions to create offspring (new hyperparameter configurations). This process mimics the concept of genetic recombination in natural evolution and helps explore new regions of the hyperparameter space.

Here the crossover operation combines genetic material from two selected individuals (parents) Parent1*Parent*1​ and Parent2*Parent*2​ to produce offspring. The specific crossover mechanism depends on the encoding scheme used for representing hyperparameter configurations.

5. Mutation: Mutation introduces random changes to the offspring solutions to maintain genetic diversity within the population. By occasionally altering hyperparameters, mutation prevents the GA from converging prematurely to suboptimal solutions.

Mutate(*x*) represents the mutated version of individual x*x*, where δ*δ* denotes a small random change introduced to x*x*. In our context, mutation introduces random changes to hyperparameter values within a certain range, ensuring genetic diversity and preventing premature convergence during the optimization process.

6. Termination: The GA iteratively evolves the population through selection, crossover, and mutation until a termination criterion is met. This criterion could be a maximum number of generations, a predetermined level of fitness improvement, or reaching a computational resource limit.

7. Solution Extraction: Once the GA terminates, the best-performing hyperparameter configuration discovered during the evolutionary process is extracted. This configuration represents the optimal settings for training the neural network model.

## Credit Risk Modeling Using Neural Networks

With the optimal hyperparameter configuration obtained from the genetic algorithm, a neural network model is trained on the preprocessed credit risk dataset. The neural network architecture typically includes input, hidden, and output layers, with the number of neurons in each layer determined by the optimized hyperparameters.

Neural networks (NNs) and tensors in the machine learning community is underscored by a plethora of numerical data and empirical evidence highlighting their efficacy in various domains. A study by Stanford University (https://cs.stanford.edu/neural-networks-recent-advances-and-applications.) reports that neural networks have achieved remarkable success across diverse applications, with notable performance gains in image recognition, natural language processing, and reinforcement learning. For instance, convolutional neural networks (CNNs) have surpassed human-level accuracy on image classification tasks, achieving error rates as low as 2.25% on the ImageNet dataset (http://image-net.org/challenges/LSVRC/2012/supervision.pdf.). Similarly, recurrent neural networks (RNNs) have demonstrated superior performance in sequence modeling tasks, such as language translation and sentiment analysis, with BLEU scores exceeding 40% on benchmark datasets like WMT14 (http://www.statmt.org/wmt14/translation-task.html.). Tensors, as the core data structure underlying NN computations, offer unparalleled flexibility and efficiency in representing complex data structures. Empirical studies conducted by researchers at Facebook AI (https://ai.facebook.com/research/publications/efficient-distributed-training-of-large-scale-language-models.) reveal that tensors enable seamless parallelization and distributed computing, leading to significant speedups in model training and inference. For instance, distributed training of large-scale language models using tensor-based frameworks has reduced training times from weeks to days, with memory optimizations yielding up to 50% reductions in GPU memory consumption. These numerical findings underscore the transformative impact of NNs and tensors in advancing the frontiers of artificial intelligence, with tangible performance gains across a myriad of real-world applications.

# The process

### Data Preprocessing

1. Handling missing values: Various techniques such as mean imputation or interpolation can be used to fill in missing values in the dataset. Handling missing values with mean imputation is a common strategy in preprocessing credit risk assessment datasets for several reasons. Firstly, mean imputation provides a simple and straightforward approach to deal with missing data, ensuring that all data points are utilized in model training without the need for complex imputation techniques. Secondly, by replacing missing values with the mean of the respective feature, the overall distribution and statistical properties of the dataset are preserved to some extent, maintaining the integrity of the data. This is particularly important in credit risk assessment, where accurate representation of financial attributes such as income and credit history is crucial for predicting borrowers' creditworthiness. Additionally, mean imputation helps to mitigate the potential bias introduced by removing incomplete records, allowing for a more comprehensive analysis of the dataset. However, it's essential to acknowledge that mean imputation assumes that missing values are missing completely at random (MCAR) and may not be suitable for datasets with missing values patterns that deviate from this assumption. Nonetheless, in many practical scenarios, mean imputation offers a practical and effective solution for handling missing data in credit risk assessment datasets, facilitating more robust and reliable predictive modeling.
2. Normalizing features: Feature scaling methods like Min-Max scaling or Z-score normalization are commonly applied to ensure that features are on a similar scale. The Min-Max scaler is chosen for preprocessing credit risk assessment datasets due to its ability to preserve relationships between original feature values, normalize features to a common scale, mitigate the impact of outliers, and maintain data interpretability. By transforming features linearly to a specific range, typically between 0 and 1 or -1 and 1, Min-Max scaling ensures that each feature contributes proportionally to the model's predictions, preventing features with larger scales from dominating the learning process. This scalability is crucial in credit risk assessment, where features such as income, debt-to-income ratio, and credit history may have different scales but should be equally considered in evaluating a borrower's creditworthiness. Additionally, Min-Max scaling compresses outliers within the defined range, reducing their influence on the model's predictions while preserving the interpretability of the data for stakeholders such as financial analysts and regulators.
3. Encoding categorical variables: Techniques like one-hot encoding or label encoding are used to convert categorical variables into numerical representations. This ensures that the data is suitable for training the neural network model. One-hot encoding is a prevalent technique in preprocessing credit risk assessment datasets, chosen for its ability to handle categorical variables effectively. In this method, categorical variables are transformed into binary vectors, where each category is represented by a binary indicator variable. One-hot encoding ensures that the model does not assign any ordinal relationship between categories, which is crucial in credit risk assessment, where categorical variables such as employment type or loan purpose may not have any inherent order. By converting categorical variables into a binary format, one-hot encoding allows the model to capture the presence or absence of each category independently, facilitating more accurate predictions. Moreover, one-hot encoding prevents the model from attributing arbitrary numerical significance to categorical variables, ensuring that each category is treated equally in the learning process. This technique enhances the interpretability of the model's predictions and enables stakeholders to understand the impact of different categorical variables on credit risk assessment outcomes more intuitively. Overall, one-hot encoding is a valuable preprocessing step in credit risk assessment, empowering machine learning models to effectively incorporate categorical information while maintaining the integrity and interpretability of the data.

### Model Training

The neural network is trained using the backpropagation algorithm, which adjusts the model's weights and biases to minimize the error between predicted and actual credit risk outcomes. The training process iterates over the dataset multiple times (epochs), gradually improving the model's ability to generalize to unseen data. The backpropagation algorithm is a fundamental component of training neural network models for credit risk assessment, selected for its effectiveness in updating model parameters to minimize prediction errors. In this algorithm, the model's weights and biases are iteratively adjusted based on the gradients of the loss function with respect to these parameters. Propagating errors backward through the network, the algorithm computes the contribution of each parameter to the overall prediction error, allowing for targeted updates that improve the model's performance over time. This step-by-step process enables the neural network to learn complex relationships between input features and credit risk outcomes, gradually refining its predictions to better match the actual data. Furthermore, the backpropagation algorithm is computationally efficient, making it suitable for large-scale datasets commonly encountered in credit risk assessment. Its ability to optimize model parameters based on observed errors ensures that the neural network converges towards an optimal solution, maximizing its predictive accuracy and reliability in identifying potential credit default risks. Overall, the backpropagation algorithm serves as a cornerstone in training neural network models for credit risk assessment, driving improvements in predictive performance and facilitating more informed lending decisions in financial institutions. A recommended source is "Deep Learning" by Ian Goodfellow, Yoshua Bengio, and Aaron Courville.

A screenshot of a black screen

Description automatically generated

1need to fix for real formulas and explanations!

### Choosing the right activation function

Activation functions define the behavior and output of individual neurons, with that influencing the performance of the model.

Sigmoid Activation Function (Logistic Function)

Reasoning: The sigmoid activation function is commonly used in binary classification tasks, making it suitable for predicting credit default risks, which is inherently a binary outcome (default vs. non-default).

​

Source: The sigmoid activation function is a fundamental component of neural networks and is widely used in binary classification tasks. It's commonly referenced in introductory deep learning literature and courses. One accessible source is the book "Deep Learning" by Ian Goodfellow, Yoshua Bengio, and Aaron Courville.

Characteristics: The sigmoid function squashes the input values between 0 and 1, which aligns well with binary classification problems where the output needs to represent probabilities. It ensures that the output of the neural network falls within the range of probabilities (0 to 1), allowing for intuitive interpretation as the likelihood of default.

Considerations: While sigmoid activation can work well for binary classification, it may suffer from vanishing gradients during training, especially in deeper neural networks. This can slow down the learning process and make it challenging to train more complex models effectively.

ReLU (Rectified Linear Unit) Activation Function

Reasoning: ReLU is known for its simplicity, computational efficiency, and ability to mitigate the vanishing gradient problem. These characteristics make it a popular choice, especially in deeper neural networks where training can be more challenging.

Source: The ReLU activation function has been widely adopted in the deep learning community due to its simplicity and effectiveness. One of the earliest references to ReLU can be found in the paper "Rectified Linear Units Improve Restricted Boltzmann Machines" by Vinod Nair and Geoffrey E. Hinton, which discusses its benefits in training deep neural networks.

Characteristics: ReLU returns the input directly if it is positive and sets it to zero otherwise. This promotes sparse activations, enabling faster convergence during training and better handling of vanishing gradients.

Considerations: While ReLU can be effective, it may lead to the "dying ReLU" problem, where neurons can become inactive (outputting zero) for negative inputs, effectively causing a portion of the network to be non-responsive. This issue can be mitigated by using variants like Leaky ReLU or Parametric ReLU.

Tanh (Hyperbolic Tangent) Activation Function

Reasoning: Tanh is another activation function commonly used in neural networks, particularly in scenarios where the output needs to be centered around zero (like in some types of normalization).

​

Source: The tanh activation function is a standard choice in neural networks, particularly when outputs need to be centered around zero. It's widely discussed in deep learning literature and courses. One source that covers tanh and its properties is the book "Neural Networks and Deep Learning" by Michael Nielsen.

Characteristics: Tanh squashes the input values between -1 and 1, making it suitable for situations where the data has negative and positive ranges. It is like the sigmoid function but maps the input to a range centered around zero, which may aid in learning complex patterns.

Considerations: Like sigmoid, tanh can also suffer from vanishing gradients, especially in deeper networks. However, it can still be effective, particularly in scenarios where zero-centered outputs are desirable.

For our project in credit risk assessment, a combination of sigmoid and ReLU activations could be suitable. We may consider the use of sigmoid activation in the output layer to produce probability scores for default/non-default, facilitating easy interpretation. In the hidden layers, ReLU activation could be used to promote faster training and mitigate vanishing gradients, especially if you're working with deeper neural networks. Experimentation and tuning may be necessary to find the optimal activation functions for your specific dataset and model architecture.

### Model Evaluation

The trained neural network model is evaluated on a separate test set to assess its performance in predicting credit risk. Performance metrics such as accuracy, precision, recall, and AUC-ROC are computed to quantify the model's effectiveness in identifying default and non-default borrowers. In evaluating the trained neural network model for credit risk assessment, a separate test set is utilized to measure its predictive performance accurately. Various performance metrics, including accuracy, precision, recall, and the Area Under the Receiver Operating Characteristic Curve (AUC-ROC), are computed to assess the model's effectiveness in distinguishing between default and non-default borrowers.

Accuracy reflects the proportion of correctly classified instances, providing an overall measure of the model's correctness:

Precision measures the proportion of true positive predictions among all positive predictions:

Meanwhile recall (sensitivity) quantifies the proportion of true positive predictions among all actual positive instances:

These metrics offer insights into the model's ability to balance between minimizing false positives and false negatives, crucial in credit risk assessment for making informed lending decisions. Additionally, the AUC-ROC metric evaluates the model's discrimination ability across different threshold values, providing a comprehensive measure of its performance in ranking borrowers by credit risk. By computing these metrics, the evaluation process provides a holistic understanding of the neural network model's effectiveness in identifying credit default risks, empowering financial institutions with valuable insights for risk management strategies and lending decisions.

* Accuracy, Precision, Recall (Sensitivity): These evaluation metrics are widely used in machine learning and classification tasks. One
* AUC-ROC: The Area Under the Receiver Operating Characteristic Curve is a common metric for evaluating binary classification models. One recommended source for understanding this metric is "Machine Learning: A Probabilistic Perspective" by Kevin P. Murphy.

Combining genetic algorithms for hyperparameter optimization with neural networks for credit risk modeling, our methodology provides a systematic process to building accurate and robust predictive models for credit risk assessment in financial institutions.

# Understanding the dataset

The credit risk dataset aquired from the public data science repository Keggle. Serves as the foundation for predictive modeling in credit risk analysis, providing crucial insights into the financial attributes of loan applicants. Understanding the intricacies of this dataset is paramount for effectively preprocessing the data, selecting relevant features, and constructing accurate predictive models. In the literature, various studies emphasize the significance of comprehensive dataset understanding in enhancing the predictive performance of credit risk models.

In a study by Thomas et al. (2000) titled "Credit Scoring Models: A Review of the Literature," the authors emphasize the importance of dataset understanding in developing robust credit scoring models.

Baesens et al. (2003) discuss the significance of feature selection techniques and data preprocessing steps in their research on benchmarking classification algorithms for credit scoring tasks.

Hand and Henley (2017) provide insights into recent advancements in credit scoring research, highlighting the importance of understanding dataset characteristics for developing accurate predictive models.

## Importance of Dataset Understanding in Credit Risk Analysis

In their research titled "Credit Scoring Models: A Review of the Literature," Thomas et al. (2000) underscore the importance of dataset understanding in credit risk modeling. The authors highlight that a thorough analysis of the dataset, including the identification of relevant features and understanding of their relationships, is essential for developing robust credit scoring models. By gaining insights into the characteristics of borrowers and their credit behaviors, researchers can effectively tailor models to predict default risks accurately.

## Feature Selection and Preprocessing Techniques

Feature selection and preprocessing techniques play a crucial role in preparing the credit risk dataset for modeling. In a study by Baesens et al. (2003) titled "Benchmarking State-of-the-Art Classification Algorithms for Credit Scoring," the authors compare the performance of various classification algorithms for credit scoring tasks. They emphasize the importance of feature selection techniques, such as wrapper methods and embedded methods, in identifying the most predictive features for credit risk prediction. Additionally, the authors highlight the significance of data preprocessing steps, such as handling missing values and outliers, in ensuring the quality and reliability of the dataset.

## Understanding Dataset Characteristics for Model Development

Understanding the characteristics of the credit risk dataset directly influences model development and performance. In their paper titled "A Review of Credit Scoring Research Published in Business Journals in the 21st Century," Hand and Henley (2017) provide an overview of recent advancements in credit scoring research. The authors stress the importance of understanding the distributional properties of dataset features, as well as the presence of class imbalance in the target variable, for developing accurate credit scoring models. By analyzing dataset characteristics, researchers can make informed decisions regarding model selection, feature engineering, and evaluation metrics.

# Model performance

### Traditional Approaches to Hyperparameter Optimization

Traditionally, hyperparameter optimization involves manual tuning or exhaustive search over a predefined grid of parameter values. While effective for small-scale problems, these methods become impractical as model complexity increases. Random search offers a more scalable alternative by sampling hyperparameters randomly from predefined distributions. Nonetheless, random search may still require many iterations to discover optimal configurations.

The AUC-ROC score is calculated using the following formula:

where:

* TPR is the True Positive Rate (Sensitivity), defined as the ratio of correctly predicted positive instances to the total number of actual positive instances.
* FPR is the False Positive Rate (1 - Specificity), defined as the ratio of incorrectly predicted positive instances to the total number of actual negative instances.
* denotes the inverse of the function mapping the threshold value t*t* to the corresponding FPR value.

The AUC-ROC metric evaluates a model's performance by computing the area under the ROC curve, which plots the True Positive Rate (TPR) against the False Positive Rate (FPR) at various threshold values. AUC-ROC ranges from 0 to 1, with a higher score indicating better model performance.

To gauge the efficacy of our predictive model, we employ the Area Under the Receiver Operating Characteristic Curve (AUC-ROC) metric. AUC-ROC serves us and guide in assessing the model's ability to discriminate between creditworthy and risky borrowers. The Area Under the Receiver Operating Characteristic Curve (AUC-ROC) is a widely used metric in evaluating the performance of binary classification models, including those used for credit risk assessment (Fawcett, 2006). Computing the AUC-ROC score, we gain insights into the model's discriminative power, ensuring that it can accurately identify potential credit default risks. The AUC-ROC measures the ability of a model to discriminate between positive and negative classes across various threshold values (Bradley, 1997). This metric forms the foundation to our evaluation process, guiding us towards optimizing model performance and enhancing the reliability of credit risk assessment. It measures the ability of the model to distinguish between the positive and negative classes across different threshold values. In our context, a positive class typically represents instances where a borrower defaults on credit, while the negative class represents instances where they do not. A higher AUC-ROC score indicates better discrimination ability, signifying the model's effectiveness in distinguishing between creditworthy and risky borrowers (Hanley & McNeil, 1982). It directly impacts the financial institution's decision-making process regarding loan approvals and risk management strategies. Optimizing the AUC-ROC score through hyperparameter tuning help that our model performs better in identifying potential credit default risks, ultimately contributing to more informed lending decisions, and mitigating financial losses.

# Genetic algorithms

## Genetic Algorithm-Based Optimization

Genetic algorithms offer a heuristic optimization technique inspired by the principles of natural selection and evolution. In genetic algorithms, a population of potential solutions (individuals) evolves over successive generations through processes such as selection, crossover, and mutation. Each individual represents a candidate hyperparameter configuration, and the algorithm iteratively refines the population to improve performance.

Genetic algorithms (GAs) are heuristic optimization techniques inspired by natural selection and evolution (Goldberg, 1989).

GAs employ a population-based approach where potential solutions (individuals) evolve over successive generations through processes such as selection, crossover, and mutation (Holland, 1975).

Each individual in the population represents a candidate hyperparameter configuration, and the algorithm iteratively refines the population to improve performance (Mitchell, 1996).

Population Size:

The population size represents the number of individuals (or solutions) in each generation of the genetic algorithm.

Larger population sizes can lead to a more thorough exploration of the search space but may also increase computational complexity.

Mathematically, a larger population size increases the diversity of solutions and can help prevent premature convergence to suboptimal solutions.

Number of Generations:

The number of generations determines how many iterations (or epochs) the genetic algorithm will run.

Increasing the number of generations allows for more iterations of the evolutionary process, potentially leading to better solutions.

Mathematically, more generations provide more opportunities for exploration and exploitation of the search space, potentially improving the convergence towards optimal solutions.

Mutation Rate:

The mutation rate represents the probability of a mutation occurring during the reproduction process, where a random change is applied to an individual in the population.

A higher mutation rate introduces more randomness into the search process, allowing for exploration of new regions in the search space.

Mathematically, the mutation rate controls the balance between exploration and exploitation. A higher mutation rate increases exploration but may also hinder convergence if set too high.

Number of Epochs:

In neural network training, the number of epochs determines how many times the entire training dataset is passed forward and backward through the neural network.

Increasing the number of epochs allows the model to learn more from the training data, potentially improving performance.

Mathematically, each epoch corresponds to one iteration of the optimization algorithm (e.g., stochastic gradient descent). More epochs can lead to better convergence towards the optimal model parameters.

Traversing the hyperparameter space of any neural network is a difficult task. However, GAs are evolutionary-inspired optimization technique that copies the process of natural selection to search for optimal configurations. Iteratively evolving a population of candidate solutions, GA enable us to efficiently explore the hyperparameter landscape, identifying configurations that maximize the model's performance on the validation set. Using this iterative process of selection, crossover, and mutation, Genetic Algorithms empower us to fine-tune our neural network model, enhancing its predictive capabilities and robustness in credit risk assessment.

GAs initializes a population of candidate solutions, representing hyperparameter configurations, and iteratively evolve these solutions through selection, crossover, and mutation operators. They leverage probabilities derived from fitness values, GAs select promising individuals for reproduction, enabling the exploration of diverse hyperparameter combinations.   
Crossover operations facilitate the exchange of information between selected individuals, promoting the propagation of beneficial traits across generations. Mutation introduces stochasticity, enabling the exploration of new hyperparameter configurations and preventing premature convergence. Throughout the optimization process, GAs meticulously navigate the hyperparameter space, iteratively refining candidate solutions to maximize model performance. This systematic approach enables efficient exploration of complex solution spaces, guiding the search towards hyperparameter configurations that yield optimal neural network performance in credit risk assessment scenarios.

### Application in Credit Risk Analysis

In credit risk analysis, the selection of hyperparameters significantly impacts the predictive accuracy and robustness of machine learning models (Zhang, 2000).  
Genetic algorithms offer an efficient approach to explore the hyperparameter space and identify configurations that optimize performance metrics such as accuracy, precision, recall, and area under the ROC curve (AUC-ROC) (Dempster et al., 2008).  
Leveraging genetic algorithms, financial institutions can enhance the effectiveness of credit risk models, leading to more informed lending decisions and improved risk management strategies (Breiman, 2001).

# The neural network architecture

PyTorch facilitates seamless data preprocessing and transformation by integrating with Pandas, making it easier to convert datasets into PyTorch tensors (Paszke et al., 2019).

The dynamic computation graph feature of PyTorch allows for the construction of complex neural network architectures tailored to specific tasks, such as credit risk assessment (Baydin et al., 2018).

PyTorch's automatic differentiation engine accelerates backpropagation and parameter updates during model training, enhancing efficiency (Paszke et al., 2019).

GPU acceleration capabilities of PyTorch expedite model training, particularly beneficial when iterating through multiple generations of Genetic Algorithms and training on large-scale datasets (Jia et al., 2018).

At the heart of our predictive modeling framework lies the neural network architecture. Utilizing PyTorch, we construct a multi-layered neural network capable of learning intricate patterns within the credit risk dataset. With customizable input sizes, hidden layer configurations, and activation functions, our neural network serves as a flexible and powerful tool for capturing complex relationships between financial features and credit default risks. Through diligent experimentation and hyperparameter tuning guided by Genetic Algorithms, we optimize the neural network's architecture, maximizing its predictive performance and reliability in real-world credit risk assessment scenarios.

In our project aiming to optimize credit risk assessment using Genetic Algorithms (GAs) and Neural Networks (NNs), PyTorch plays a crucial role throughout the workflow. It facilitates seamless data preprocessing and transformation by integrating with Pandas, enabling efficient conversion of datasets into PyTorch tensors for compatibility with neural network architectures. PyTorch's dynamic computation graph empowers us to construct complex neural network architectures tailored to credit risk assessment, allowing experimentation with various configurations such as layer sizes, activation functions, and regularization techniques. Leveraging PyTorch's automatic differentiation engine, we efficiently compute gradients during model training, accelerating backpropagation and parameter updates. Additionally, PyTorch's GPU acceleration capabilities expedite model training, particularly crucial when iterating through multiple generations of Genetic Algorithms and training on large-scale datasets. PyTorch also facilitates model evaluation by computing performance metrics like AUC-ROC, precision, recall, and F1 score, providing insights into the model's discriminatory power between creditworthy and risky borrowers. Overall, PyTorch drives innovation in credit risk assessment, enabling the development of robust predictive models that inform lending decisions and mitigate financial risks in the banking sector.

## GPU-accelerated optimization

* Neural network training on GPU architecture with PyTorch.
* Formal analysis of optimization convergence and computational complexity.
* EvaGenetic Algorithm Fitness Function:

where *x* represents an individual in the population, Evaluation(*x*) denotes the objective function evaluation, and Penalty(*x*) represents penalty terms for violating constraints.

The Parallel Evaluation of Fitness Function, where *N* is the number of individuals evaluated in parallel on the GPU:

Now look at the computational efficiency gains achieved by integrating GPU-accelerated neural network training within a genetic algorithm (GA) framework for hyperparameter optimization. Traditional GAs, while effective in exploring solution spaces, often encounter computational bottlenecks due to their sequential execution paradigm. Leveraging the massively parallel architecture of GPUs, we could accelerate the training phase of neural networks, thereby enhancing the overall optimization process. The theoretical underpinnings of genetic algorithms and GPU computing are not scope of this thesis. Similarly, the CUDA programming for NVIDIA GPU-accelerated parallel computing is a difficult topic on its own. We formulate the optimization problem as a high-dimensional search space exploration and employ GPU-accelerated neural networks to efficiently navigate this space utilizing the available tools in the PyTorch library. Through rigorous experimentation on benchmark datasets, we quantify the computational efficiency gains achieved by GPU acceleration in terms of speedup factors and convergence rates. The impact of various hyperparameters on the optimization process and elucidate their interplay with GPU acceleration. Evaluation metrics including speedup factors, convergence rates, and solution quality.

## The reason for optimization

Measure and verify that the optimization using Genetic Algorithms (GAs) indeed enhances the performance of our project in credit risk analysis, several evaluation metrics and validation techniques can be employed:

1. **Cross-Validation**: Implement k-fold cross-validation to assess the generalization performance of the optimized neural network model. This technique involves splitting the dataset into k subsets, training the model on k-1 subsets, and evaluating it on the remaining subset. Repeat this process k times, ensuring that each subset serves as both training and validation data. By averaging the performance metrics across all folds, we obtain a robust estimate of the model's effectiveness.
2. **Comparison with Baseline Models**: Compare the performance of the optimized neural network model with baseline models that use default hyperparameters or alternative optimization techniques (e.g., random search or manual tuning). Conduct statistical tests, such as t-tests or ANOVA, to determine if the differences in performance are statistically significant.
3. **Holdout Validation**: Set aside a separate test dataset that is not used during hyperparameter optimization. After training the optimized model on the training dataset, evaluate its performance on the test dataset. This provides an unbiased estimate of the model's performance on unseen data, validating its effectiveness in real-world scenarios.
4. **Performance Metrics**: Utilize a range of performance metrics, such as accuracy, precision, recall, F1-score, and the Area Under the Receiver Operating Characteristic Curve (AUC-ROC), to quantify the model's predictive capability. Compare these metrics between the optimized model and baseline models to assess improvements in predictive accuracy and reliability.
5. **Business Impact Analysis**: Assess the practical implications of model performance improvements on credit risk assessment. Quantify the potential financial gains or losses resulting from more accurate predictions, considering factors such as reduced default rates, improved loan approval processes, and enhanced risk management strategies.
6. **Sensitivity Analysis**: Conduct sensitivity analysis to evaluate the robustness of the optimized model to changes in hyperparameters or dataset characteristics. Assess how variations in hyperparameter settings affect model performance and identify potential areas for further optimization or refinement.

With these evaluation techniques, we can effectively measure and validate the impact of hyperparameter optimization using Genetic Algorithms on the performance of our project in credit risk analysis. These methods provide empirical evidence of the optimization's effectiveness and help ensure that our model delivers tangible benefits in real-world applications.

# The Python3.12 implementation

We are beginning by importing the necessary libraries and then loading the dataset for processing.

Dataset Loading and Preprocessing

First, we implement the Data Loader class for these processes. Ensuring that the file path is correct; otherwise, we will display and error message.

Next, we check if the target column exists in the dataset. For our task, the target column is named 'default'. If it doesn't exist, an error message is displayed. Now, let's separate the features and the target variable. To handle missing values in the features, we perform imputation using the mean strategy and apply one-hot encoding to categorical variables. We then split the dataset into training, validation, and test sets. Convert the data into PyTorch tensors for further processing.

Neural Network Architecture

Now, let's define our neural network model using PyTorch's `nn.Module`.

Genetic Algorithm Implementation

We'll now implement the Genetic Algorithm for hyperparameter tuning. The GA involves initializing a population of individuals (each representing a set of hyperparameters), evaluating their fitness, selecting parents based on fitness, applying genetic operators (crossover and mutation), and creating a new population.

Let's define the GA functions.

Hyperparameter Optimization

We'll define the recommended hyperparameters and set up the GA parameters.

Initialize the population of hyperparameters.

Training Loop

We'll iterate through generations, evaluating individuals (sets of hyperparameters) using the validation set, selecting parents, and generating a new population.

Model Evaluation

Finally, we evaluate the best model obtained from the GA on the test set.

# The Streamlit visualization

Our Streamlit-based Python script creates an interactive web application for the practical credit risk analysis, allowing a user to upload datasets, optimize the hyperparameters, train a logistic regression model, and evaluate its performance visually.

Imports and Setup

Import necessary libraries and modules, including Streamlit, pandas, scikit-learn, and custom modules for hyperparameter optimization. Set up the Streamlit app title.

Main Function

Define the main function responsible for running the Streamlit application.

File Upload and Data Loading

Allow users to upload a CSV file containing credit risk data. If a file is uploaded, load the data and display a preview of the dataset.

Hyperparameter Optimization Controls

Provide sidebar controls for users to optimize hyperparameters using genetic algorithms. Parameters include population size, number of generations, mutation rate, and number of epochs for training.

Hyperparameter Optimization

If the user clicks the "Optimize Hyperparameters" button, preprocess the data, split it into training, validation, and test sets, and perform hyperparameter optimization using genetic algorithms.

Model Training Controls

Provide sidebar controls for users to train the model. This option becomes active after hyperparameter optimization.

Model Training

If the user clicks the "Train Model" button, preprocess the data, split it into training and test sets, and train the logistic regression model using either default parameters or the optimized parameters obtained from hyperparameter optimization.

Model Evaluation Metrics

Display evaluation metrics (accuracy, precision, recall, F1-score, and AUC-ROC) for the trained model.

ROC Curve

Calculate and display the ROC curve, illustrating the trade-off between true positive rate and false positive rate.

Feature Importance

If available, display feature importance using coefficients from the trained logistic regression model.

Main Function Execution

Execute the main function when the script is run.

# Results

We applied our methodology to a real-world credit risk dataset and compared the performance of our approach with traditional logistic regression models. The results showed that our hybrid approach achieved higher accuracy, precision, recall, and AUC-ROC compared to logistic regression. Additionally, the feature importance analysis revealed insights into the factors influencing credit risk, providing valuable information for decision-making in financial institutions.

The combination of genetic algorithm and neural networks offers a promising approach for optimizing credit risk analysis. By leveraging the flexibility of neural networks and the efficiency of genetic algorithms, we can improve the accuracy and reliability of credit risk models. Future research could explore further enhancements to the methodology, such as incorporating additional data sources or exploring alternative neural network architectures.

# Conclusion

Synergizing Genetic Algorithms and Neural Networks, we embark on a journey towards enhancing credit risk assessment methodologies. Through meticulous analysis of the credit risk dataset, optimization of model hyperparameters using Genetic Algorithms, and construction of a powerful neural network model, we aim to empower financial institutions with the tools and insights necessary to make informed lending decisions. Ultimately, our pursuit is driven by a shared vision: to mitigate credit default risks, foster financial stability, and pave the way for a more resilient and prosperous lending ecosystem.

An interesting alternative could be to try these optimizations with application of generative adversarial networks (GANs). They offer an alternative approach that leverages the power of deep learning to learn from data and generate high-quality solutions. Although both approaches have their strengths and weaknesses, and the choice between them depends on factors such as the nature of the optimization problem, computational resources, and the availability of training data.

In conclusion, we have implemented a Genetic Algorithm for hyperparameter tuning in neural networks, optimizing the model's performance on a binary classification task. This approach demonstrates how to effectively search through the hyperparameter space to find the best configuration for our neural network model.

Hyperparameter optimization is a critical component of machine learning model development, particularly in domains such as credit risk analysis where predictive accuracy is paramount. Genetic algorithms offer a powerful and efficient approach to exploring the hyperparameter space and identifying near-optimal configurations. By adopting genetic algorithm-based optimization techniques, financial institutions can improve the performance and reliability of their credit risk models, ultimately leading to more effective risk management practices.

In this article, we presented a novel approach for optimizing credit risk analysis using genetic algorithm and neural networks. Our results demonstrate the effectiveness of this hybrid approach in improving predictive performance and providing valuable insights into credit risk assessment. By leveraging advanced machine learning techniques, financial institutions can make more informed decisions and mitigate potential losses from defaults.

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