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NFT Authentication Methods and Big Data

Kandidat: Emil Leifer

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Mentor predavatelj: Mag. Ervin Schaff

Mentor v podjetju: Petra Munda

Lektorica: dr. Tina Balič

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IZJAVA O AVTORSTVU DIPLOMSKEGA DELA

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1 INTRODUCTION

1.1 Introduction to the topic

The modern world is experiencing a digital asset revolution, and one of the most important innovations are non-fungible tokens (hereinafter NFTs). Despite the relative youth of this technology, it has already managed to generate a wave of interest and attract the attention of both users and investors. NFTs are unique digital assets that can be used to represent unique items, artwork, gaming paraphernalia, and other digital properties on blockchain platforms.

However, along with the growing popularity of NFTs, several difficulties and problems have arisen that require attention and research. In this diploma thesis, our goal is to address one of the key issues associated with NFTs, namely the authentication of these digital assets on the Worldwide Asset eXchange platform (hereinafter WAX).

WAX, as a blockchain platform, provides a unique environment for the creation and exchange of NFTs, and therefore attracts many users. However, as the number of NFTs created increases, their authentication becomes progressively challenging.

Existing methods of NFT authentication on the WAX platform have their limitations. They are usually limited by technical parameters of the tokens, such as hashes or signatures, and are not always able to provide a complete insight into the true nature of the asset. This leaves users exposed to potential security threats such as fraud and NFT counterfeiting.

It is important to be aware of the growing popularity of NFTs as an investment and artistic medium. Users and investors are increasingly using NFTs to represent and exchange unique values. In this regard, the security and authentication of NFTs are becoming critical aspects, affecting the trust in this technology and the long-term stability of the market.

Big data analysis and the application of machine learning techniques can provide new tools and techniques for a more secure NFT authentication on the WAX platform. Understanding the magnitude of this problem and its importance is a motivating factor for further research and development of new authentication methods that can ensure the security and efficiency of using digital assets on a blockchain platform.

1.2 Purpose and objectives of the study

The purpose of this thesis is to research and develop big data analytics techniques to improve NFT authentication and identify trends in the NFT market on the WAX platform.

To achieve this goal, the following tasks were set:

- **Analysing the existing NFT authentication methods and identifying their limitations:** The first step in the research is to analyse the current methods used to authenticate NFTs on the WAX platform. This includes examining the technical parameters of the authentication process, such as hashes and signatures, as well as identifying their strengths and weaknesses.
- **Exploring the use of big data and machine learning techniques to improve NFT authentication methods:** The second objective is to explore how big data and machine learning techniques can be applied to improve authentication. This includes exploring modern big data analytics and machine learning techniques that can be adapted to the NFT context on the WAX platform.
- **Developing and testing new methods to identify NFTs, especially using big data analysis:** The third task is the actual development of new authentication methods based on the big data analysis. This includes creating new algorithms and authentication approaches that consider a wider range of data and context.
- **Analysing big data on transactions, metadata, and user activity in the NFT market to identify trends and popular token types:** The final task is to analyse big data collected from the WAX platform to identify trends and popular NFT types. This will allow us to understand which assets are most in demand on the market and what factors influence their value (Oracle).

1.3 Development of the hypotheses

To achieve the goals and solve the assigned tasks, the following hypotheses were formulated within the framework of this thesis:

1. **H1: The existing methods of NFT authentication on the WAX platform have their limitations that can be overcome through big data analytics:** We hypothesised that the existing authentication methods do not always provide complete security and can therefore be improved through big data analytics.

2. **H2: The use of big data analytics and machine learning techniques will lead to the development of more effective NFT authentication methods on the WAX platform:** We hypothesised that the use of big data analytics and machine learning techniques can increase the reliability of the authentication methods.

3. **H3: Developing and testing new NFT authentication methods based on big data analytics will increase the security and efficiency of using NFTs on the WAX platform:** We hypothesised that new authentication methods developed based on big data analytics can make the use of NFTs on the WAX platform safer and more effective.

4. **H4: Big data analysis of transactions, metadata, and user activity will help identify trends and popular types of NFTs on the WAX platform:** We hypothesised that the big data analysis can help identify the assets that are most popular among the WAX platform users and key factors influencing their value.

2 LITERATURE REVIEW

This chapter of the thesis provides a literature review on the NFT authentication on the WAX platform. The entire review will help understand the current state of the topic, identify key methods and approaches, and highlight open or outstanding problems and directions for further research.

2.1 Overview of the existing NFT authentication methods on the WAX platform

NFT authentication on the WAX platform is critical in ensuring the safety and security of trading and storing digital assets. This section will review the existing authentication methods and their importance in combating counterfeiting and fraud. Key aspects will be assessed in the following areas:

- **Cryptographic Authentication Methods:** An analysis of methods that use cryptographic technologies, such as digital signature and hashing, to ensure the security of NFTs on the WAX platform.
- **Accounts and Multi-Factor Authentication:** Explore user account-based and multi-factor authentication methods to secure NFTs on the WAX platform.
- **Smart Contracts and Blockchain:** Considering the use of smart contracts and blockchain technology to authenticate NFTs on the WAX platform (Christidis, 2016).
- **Risk and Vulnerability Analysis:** Analyse the risks and vulnerabilities associated with the existing authentication methods to better understand potential threats to the security of NFTs on the WAX platform.

2.1.1 Digital signature in the authentication of NFTs

Electronic digital signature (EDS) is a cryptographic authentication method widely used in the security of digital assets. The use of the digital signature can be a key element in ensuring the security of NFTs on the WAX platform.

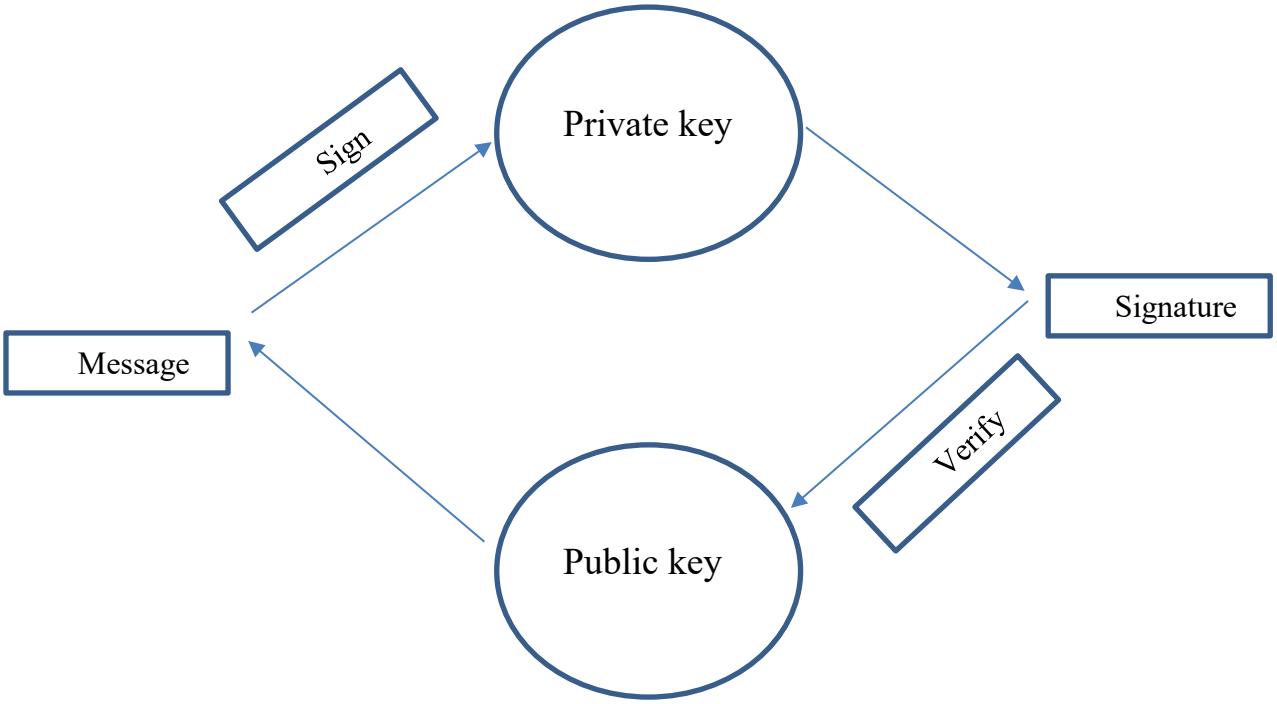


Figure 1: Explanation of the transaction process

Source: Own Source

- **Operating principle of digital signature:**

The digital signature consists of two keys, closed (private) and open (public). The user signs the data using his private key, and other users can authenticate the data using his public key.

- **Applicability on the WAX platform:**

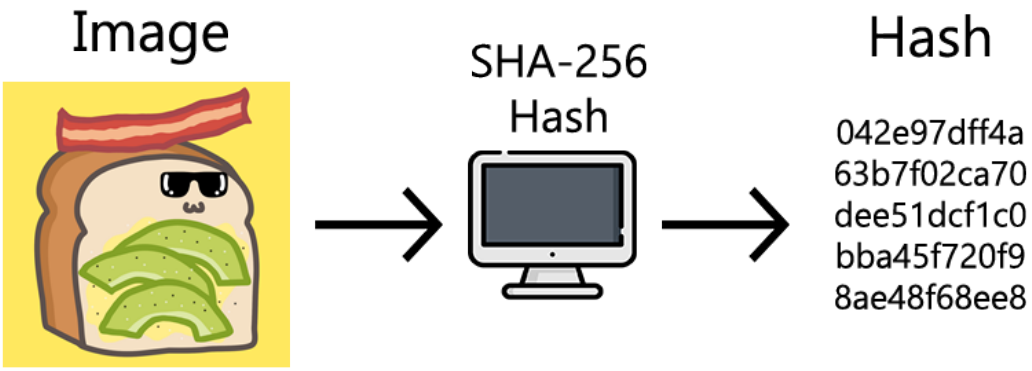
In the context of WAX, a digital signature can be used to sign transactions involving NFTs. This ensures that only the owner of the private key can perform operations on the tokens, such as a transfer or sale. This ensures a strong authentication of the NFT owners on the platform.

- **Efficiency mark:**

Digital signature is one of the most reliable authentication methods, providing a high level of protection against unauthorised access.

2.1.2 Hashing in NFT authentication

Hashing is another cryptographic method that can be used to ensure the security of NFTs on the WAX platform.



Picture 1: How the NFTs get hashed

Source: (Lee, 2021)

- **How hashing works:**

Hashing is the process of converting data into a fixed set of characters (hash), which serves as a kind of "fingerprint" of the data. Hashing is useful for checking data integrity.

- **Applicability on the WAX platform:**

Hashing can be used to authenticate NFT metadata. Each token can have its own metadata hash, which is stored on the WAX blockchain. If one tries to change the token metadata, the hash will also change, signalling a possible fraud attempt.

- **Efficiency mark:**

Hashing provides effective authentication of data integrity and detection of unauthorised changes. This method is easily scalable and requires minimal computing resources to generate and verify hashes (Lee, 2021).

2.1.3 Comparison of cryptographic authentication methods on the WAX platform

For a deeper understanding, a comparative analysis between two cryptographic authentication methods, i.e., digital signature and hashing, was conducting, as presented below. Both methods can be applied in the context of NFTs on the WAX platform to ensure security.

Criterion	Digital signature	Hashing
Applicability on the WAX	*Used for:* To authenticate users transacting NFTs on the WAX.	*Used for:* To authenticate metadata and token integrity on the WAX.
Efficiency and benefits	Provides a high level of safety and reliability.	Easy to implement and provides quick data integrity verification.
Restrictions	May require computing resources to generate and verify signatures.	Does not provide user authentication.
Sharing	In some cases, for maximum security, the combined use of digital signature and hashing may be considered.	-

Table 1: Comparing digital signature and hashing

Source: Own Source

2.1.4 Risks and threats in using cryptographic authentication methods

It is also necessary to consider the risks and threats associated with the use of cryptographic authentication methods to fully understand how to ensure the security of NFTs on the WAX platform.

Risks and threats in using digital signatures:

- **Lost private key**: If a user loses his private key, it may result in him being unable to access his NFTs.
- **Private key compromise:** If an attacker gains access to a private key, he can perform operations on behalf of the token owner.

Risks and threats in using hashing:

- **Data manipulation:** Hashes can be vulnerable to attacks if an attacker is able to change the data and still generate a new valid hash.
- **Hash guessing:** With the help of powerful computing resources, attackers can attempt to find the correct hash to modify data.

Risk mitigation measures:

- **Multi-factor authentication (MFA):** To reduce the risk of losing or compromising private keys when using digital signatures, MFA can be implemented (EOS-Amsterdam).
- **Key backups:** Regularly backing up private keys and storing them in secure locations will help prevent data loss.

2.1.5 User accounts and cryptography on the WAX platform

On the WAX platform, user accounts and cryptography focus on ensuring secure interactions with NFTs and other digital assets. This happens without strict dependence on traditional logins and passwords, since the system is based on crypto wallets. A closer look at how this works is provided below:

Crypto wallets and keys:

- Instead of logins and passwords, users on the WAX platform work with crypto wallets, which contain cryptographic keys.
- **Public and private keys:** Each crypto wallet contains a pair of keys – public and private. The public key is used to verify transaction signatures whereas the private key is used to create signatures.

Authentication process:

- Users are authenticated by signing transactions using their private key. This allows WAX to verify their authenticity without requiring traditional logins and passwords.
- To perform transactions such as transferring NFTs or participating in auctions, users sign transactions using their private key, and the WAX system verifies their signature to authorise the transaction.

Secure key management:

- An important part of the system is the secure key management. Private keys must be kept in a secure place and should not be disclosed. This ensures the safety of the users' assets.

Logging and auditing:

- All transactions signed by the user are recorded on the WAX blockchain. This provides logging and auditing of all transactions that can be traced using public keys.

Advantages of crypto wallets:

- **Security:** Crypto wallets provide a high level of security, since access to assets is carried out through signatures using cryptographic keys.
- **No need for logins and passwords:** The absence of traditional logins and passwords eliminates the risks associated with their leakage or loss.
- **Transparency and audit:** Blockchain ensures transparency and audit of all transactions, which contributes to the security and trust of users.

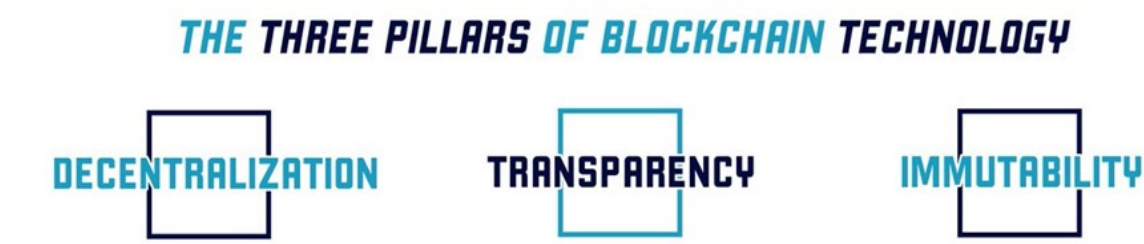
2.1.6 Smart contracts and blockchain in the EOSIO ecosystem for the authentication of NFTs on the WAX platform

Smart contracts and blockchain technology play an important role in ensuring the security and authentication of NFTs on the WAX platform based on the EOSIO ecosystem. In this section, we will look at how these tools provide security and reliability for trading and storing digital assets (Christidis, 2016).

Smart contracts on the WAX platform:

- Smart contracts on the WAX platform are software codes that run on the EOSIO blockchain. They provide the ability to create rules and conditions for performing transactions with NFTs.
- Authentication using smart contracts: Smart contracts can be configured to verify the authenticity of a user before allowing access to certain functions or assets. This may include verifying transaction signatures using cryptographic keys.
- Permissions and roles: Smart contracts allow setting different levels of permissions and roles for the users. This means that only certain users with certain rights can perform certain operations with NFTs.

Advantages of the EOSIO blockchain:



Picture 2: Advantages of the EOSIO blockchain

Source: https://twitter.com/block_bank/status/1153394596405272576

- **Decentralisation:** EOSIO is a decentralised blockchain platform, meaning there is no single point of failure and a higher resistance to attacks.
- **Immutability:** Data stored on the EOSIO blockchain cannot be changed without the consent of most network participants. This ensures the integrity and security of NFTs.

- **Transparency:** All transactions and actions on the EOSIO blockchain are public and verifiable. This promotes transparency and trust in the system.

Application of blockchain technology:

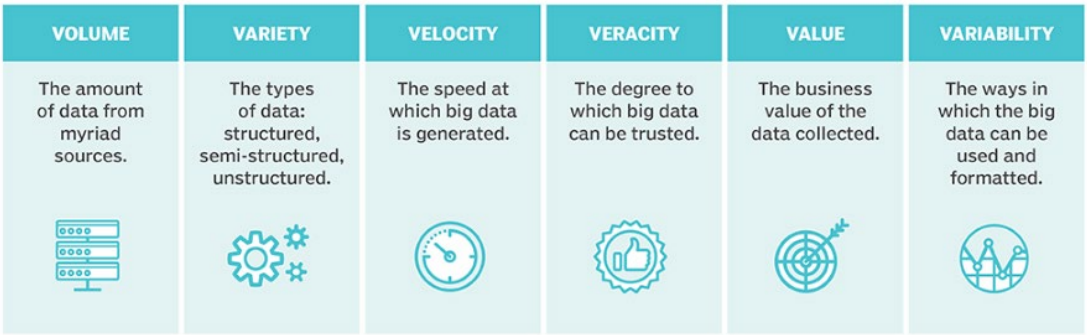
- **Tracking and transaction history:** The EOSIO blockchain records every transaction involving NFTs on the block chain. This provides transaction history and the ability to track the origin and movement of each token.
- **Consensus and security:** The consensus mechanisms of the EOSIO blockchain ensure network security and protection from attacks. This significantly increases the level of trust in the NFT authentication system.

2.2 About big data

2.2.1 Introduction to big data

In the modern world, digital assets and cryptocurrencies are rapidly growing, playing a crucial role in the economy. Data take centre stage, becoming an indispensable part of management and analysis. Big data refers to vast and complex sets of information that require specialised tools for an effective analysis. In this section, we will explore how big data has become an integral part of the NFT authentication process on the WAX platform, and how these data ensure the security and authenticity of tokens.

In the context of NFT authentication on the WAX platform, the role of big data becomes even more significant, especially in the context of the six key characteristics known as the 6Vs. These characteristics include:



Picture 3: 6VS Characteristics

Source 3: https://edurev.in/t/212629/Big-Data

Volume: Processing the immense volume of data generated by millions of transactions and user interactions on the WAX platform requires robust systems and tools. Big data enables efficient scaling of data processing and storage, ensuring high performance, even with substantial data volumes.

Variety: Dealing with diverse data formats, such as digital signatures and user attributes, demands flexibility in processing and analysis. Big data tools like NoSQL databases provide flexible storage, and retrieval of heterogeneous data are crucial to the successful authentication of NFTs.

Velocity: Real-time analysis and response to user activity become critically important. Technologies such as Apache Spark allow for high-speed data processing, necessary for timely identification of anomalies and suspicious events.

Veracity: Data accuracy is a key aspect when confirming the authenticity of NFTs. Big data technologies, including data verification mechanisms and accuracy assurance methods, ensure that the data used for authentication are reliable and trustworthy.

Value: Extracting valuable information from data contributes to enhancing the efficiency of the authentication system. Machine learning methods and data analysis algorithms help identify patterns and provide valuable insights that can be used to improve the authentication process.

Vitality: Maintaining data relevance in the rapidly changing world of digital assets and cryptocurrencies is crucial. Big data technologies provide mechanisms for real-time data updates, supporting the timeliness of information in the NFT authentication system.

2.2.2 The role of big data in NFT authentication

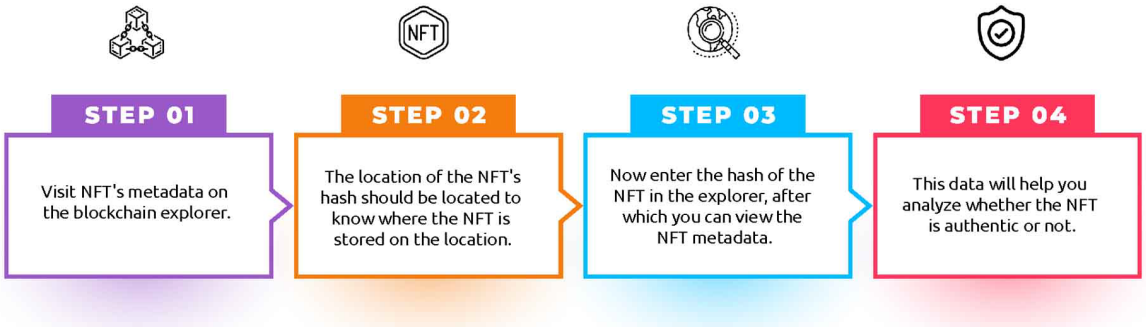
Authentication of NFTs on the WAX platform is complex and requires robust mechanisms and tools. In this context, big data plays an important role:

- *Anomaly and suspicious activity analysis:* One of the key aspects of authentication is the detection of anomalies and suspicious activity. Big data allows tracking and analysing user activity and transactions, identifying unusual or suspicious patterns. This can help prevent fraud and unauthorised access.

- *Identification of unique patterns:* For security purposes, big data can identify unique patterns and characteristics of user behaviour. This may include detecting unique digital signatures or user attributes that can be used for authentication.
- *Scalability:* The WAX platform serves many users and millions of transactions. Big data can process such volumes of information, ensuring scalability of the authentication system.

2.2.3 Integration of NFT and big data

The modern digital economy is closely related to the NFT technology, which is a unique digital asset with unique value. The ever-growing market of digital assets, including collectibles, art, music, and virtual lands, has become a key factor in the development of the NFT technology. It ensures the uniqueness and authenticity of each asset, giving owners confidence in its originality.



Picture 4: Steps to obtain NFT data

Source: https://coinfactory.tech/nft-authentication-how-can-nfts-solve-authentication-problems-in-blockchain/

However, as NFTs grow in popularity and the number of digital assets increases, so do the challenges of authenticating such tokens. Particularly on the WAX platform where users conduct many transactions, authentication becomes a complex task requiring robust mechanisms and tools.

Authentication of NFTs on the WAX platform must pay special attention to the following complexities:

Ensuring authenticity: Each NFT has a unique digital signature and ID, making it original. Authentication must confirm that each token is what it claims to be.

Owner identification: Ensuring that only legitimate owners have access to their digital assets is key. This prevents unauthorised access and fraud.

In this context, big data plays an important role:

Anomaly and suspicious activity analysis: One of the key aspects of NFT authentication is the detection of anomalies and suspicious activity. Big data allows the system to track and analyse user activity and transactions in real time, identifying unusual or suspicious patterns. This helps prevent fraud and unauthorised access.

Identifying unique patterns: For security purposes, big data helps identify unique patterns and characteristics of user behaviour. This may include discovering unique digital signatures or user attributes that can be used for authentication. This level of personalisation increases the reliability of the authentication system.

Scalability: The WAX platform serves a huge number of users and handles millions of transactions. Big data has the unique ability to process such volumes of information without impacting the performance. This ensures that the authentication system is scalable and can serve a huge number of users with high efficiency.

The integration of big data and NFT technology becomes important in ensuring the reliability and security of digital assets on the WAX platform. It allows for an effective analysis and monitoring of users' activities, detecting anomalies and unique characteristics, which ensure the authenticity and security of NFTs.

2.2.4 Technologies for processing and analysing big data

To effectively use big data in NFT authentication, it is necessary to use appropriate technologies and tools:

- *Hadoop:* It is a framework for processing and analysing big data that can be used for distributed storage and processing of information. It provides high availability and fault tolerance of data.
- *Apache Spark:* It is a powerful tool for processing big data in real time. It allows complex calculations and analyses on a large volume of data at high speed.
- *NoSQL databases:* For example, MongoDB or Cassandra, provide flexible and scalable solutions for storing and analysing large volumes of data.
- *Machine learning methods:* For example, classification and clustering can be applied to data to identify anomalies and create authentication models.

Effective use of these technologies allows the WAX platform to provide a strong authentication of NFTs and increase the security of digital assets for its users.

2.3 Researching trends and types of NFTs based on big data analysis

2.3.1 Trends in the NFT world

Researching trends in the NFT world is an integral part of the NFT authentication strategy on the WAX platform. Data analysis allows us not only to understand current trends, but also to predict future changes in user preferences. Monitoring trends allows authentication methods to be better tailored to the changing demand for different types of NFT assets.

Key aspects of trend research include:

- **Analysis of the number and value of NFT transactions:** Studying the dynamics of sales and prices for NFT assets allows us to identify the most popular categories and criteria of value among users.
- **Identification of popular NFT collections:** Identifying the most successful and sought-after NFT collections helps understand what types of assets most often attract the attention of collectors.
- **Media activity research:** An analysis of the NFT mentions in the media and social networks helps determine what events and news influence interest in NFT assets.
- **Researching vents and auctions:** Analysis of the results of auctions and events related to NFTs allows us to identify successful sales strategies and asset categories that attract the attention of investors.

2.3.2 Types of NFT tokens

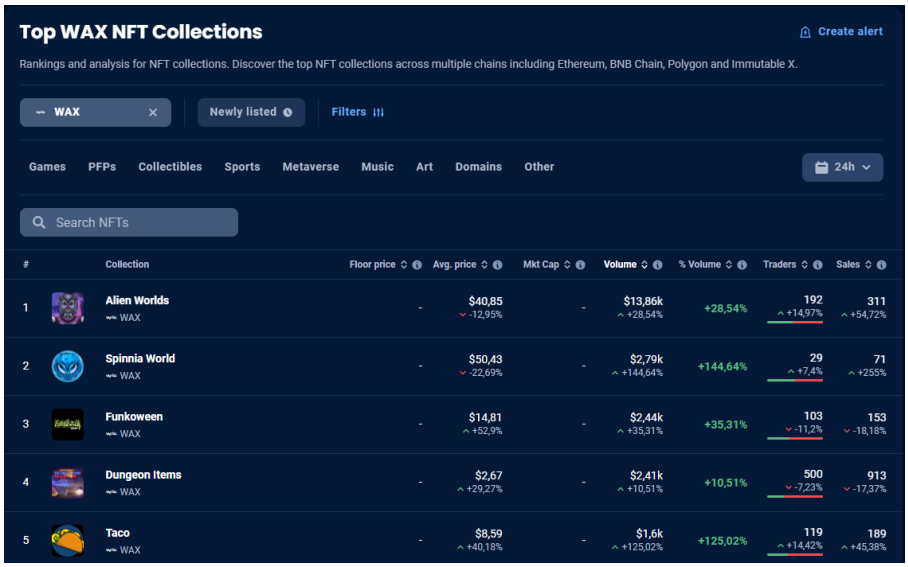
NFT tokens on the WAX platform have a variety of real-world applications that span a variety of industries. Here are some examples of using NFTs on the WAX platform:

- **Collecting and art:** The WAX platform allows artists and collectors to create and sell digital works of art in the form of NFTs. This opens new opportunities for artists to promote their creative work and get rewarded for their efforts. Collectors can purchase unique and valuable digital art that can be stored and traded as valuable assets.

- **Game industry:** Virtual items, characters, and assets from games can be represented as NFTs on the WAX platform. This adds value to in-game assets and allows players to trade them on the open market. Gaming NFTs can also be used in various games, enhancing the gaming experience.
- **Sports and entertainment:** On the WAX platform, one can create and sell sports NFTs, such as digital athlete cards or moments from sporting events. These NFTs could be of interest to sports fans and collectors. In addition, they may provide access to unique events or content, related to a specific sports club or player.
- **Virtual worlds:** Virtual worlds such as virtual lands and real estate can be represented as NFTs. This opens opportunities to create and manage virtual assets that can have real value. For example, virtual worlds on a decentraland platform use NFTs to sell and lease virtual land plots.
- **NFT utilities:** Some NFTs on the WAX platform may provide utility functions. For example, NFT utilities can provide access to exclusive content, events, or bonuses in the apps and games, making them more attractive to the users.

In real world the application of NFTs on the WAX platform allows for the creation of unique and valuable digital assets that can be used, collected, and traded. It also promotes the development of new business models and opportunities for artists, game developers, and other creative industries.

Researching the different types of NFTs helps us better understand what attributes and features of these tokens can be used to improve authentication on the WAX platform and ensure user security.

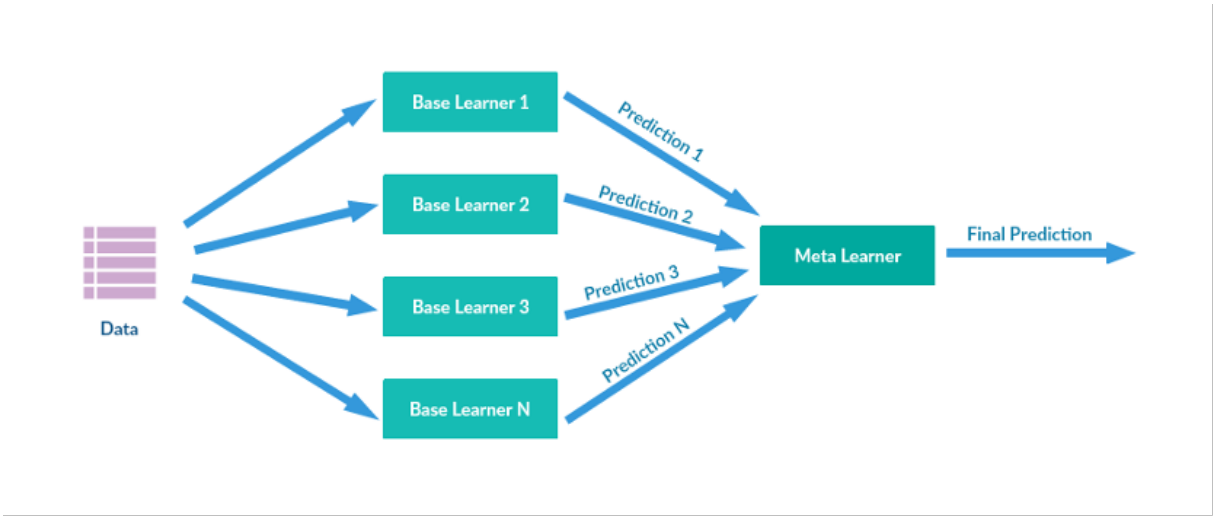


Picture 5: Top collections on the WAX by sales

Source: https://dappradar.com/rankings/nft/collections/chain/wax?range=week

2.4 Applying machine learning and big data analytics to improve NFT authentication on the WAX platform

This chapter looks at how the use of machine learning and big data analytics can improve the NFT authentication process on the WAX platform. These technologies make authentication more accurate, reliable, and adaptive.



Picture 6: How to improve machine learning

Source: https://vannguyen-8073.medium.com/stacking-classifiers-for-higher-predictive-cancer-diagnosis-7021075ce21c

2.4.1 Introduction to **machine learning and big data analytics**

Machine learning: It is a field of artificial intelligence that allows computers to learn from data and make decisions without explicit programming. This includes classification, regression, clustering, and reinforcement learning methods.
Big Data Analysis: It means extracting useful information from large volumes of data to identify patterns, trends, and anomalies. This process often involves data processing, visualisation, and modeling (Anirban Mukherjee, 2018).

2.4.2 Using machine learning to authenticate NFTs

User classification: By using machine learning techniques, users can be classified based on their behaviour and characteristics, which allows us to detect anomalies in activities and identify potential attackers.
Anomaly detection: Supervised and unsupervised learning algorithms can be used to detect anomalous activities, such as unusual attempts to access NFTs.

2.4.3 Using big data analytics to authenticate NFTs

Search for patterns: Big data analysis allows us to identify patterns in user activities that can be used for authentication. This may include analysis of time series, sequences of events, and correlations between data.
Risk Forecasting: Big data analysis helps in predicting potential risks and threats, which allows proactive measures to be taken to protect NFTs.

2.4.4 Application on the WAX platform

The WAX platform has implemented systems that use machine learning and big data analytics to improve the authentication of NFTs. These systems analyse user activity, detect anomalies, and provide more accurate and reliable authentication. Every transaction and interaction with NFTs is analysed to identify potential threats and prevent unauthorised access.

The use of machine learning and big data analytics on the WAX platform improves the security and reliability of NFT authentication, which is critical due to the growing popularity of NFTs and digital assets. However, there are challenges such as processing large volumes of data and

ensuring the privacy of user information that require careful consideration and solutions (Anirban Mukherjee, 2018).

3 RESEARCH METHODOLOGY

3.1 Selection and description of the research approach

3.1.1 Choice of research approach

Before the study began, a variety of research approaches had been considered, including both qualitative and quantitative methods, and analytical and experimental approaches. However, given the nature of the task associated with improving the authentication of NFTs as well as the need to analyse large volumes of data, a mixed research approach was chosen that combines big data analysis and machine learning methods.

The choice of this approach was justified by the need to analyse user activity on the WAX platform, identify anomalies and ensure reliable authentication. To solve this problem, it is necessary to process large volumes of data, identify patterns and changes in user behaviour, and identify potential risks. Machine learning and big data analytics are the most suitable tools for this task.

3.1.2 Description of the chosen research approach

- **Approach and methods:** The chosen research approach includes big data analysis techniques such as data mining, pattern searching, and time series analysis. We have also used machine learning techniques to classify users, detect anomalies, and predict risks.
- **Scope:** This approach is applicable to the task of improving the authentication of NFTs on the WAX platform, as it allows us to analyse user activity, identify anomalies and risks, and adapt the authentication system in real time.
- **Advantages of the chosen approach.** The chosen approach allowed us to extract valuable knowledge from large volumes of data, to improve the authentication process, and prevent potential threats. We will be able to classify users based on their behaviour and apply machine learning techniques for more accurate authentication.
- **Limitations and expected challenges.** The research will address the challenges of processing large volumes of data, maintaining confidentiality of information and

training models in a changing threat environment. However, we are ready to overcome these challenges with the help of advanced data analysis and machine learning techniques and tools.

In the empirical part of the thesis, we will use a quantitative research approach to analyse the state and development potential of the NFT market on the WAX platform. We have analysed existing projects and research in the field of NFT on the WAX platform, studied trends and tendencies in the development of this market. An analysis of data related to the NFT transactions, user activity and other factors will be conducted to identify key features and opportunities to improve user experience.

Thus, the research area includes the following aspects:

- development of applications on the WAX blockchain, specifically related to NFTs;
- security and vulnerability in the development and trading of NFTs on the WAX platform;
- analysis of the state and development potential of the NFT market on the WAX platform.

Furthermore, it is imperative to underscore that our comprehensive data analysis was conducted exclusively through the examination of transactions recorded on the blockchain. No information was retained or stored; instead, it was dynamically processed based on specific informational requirements. This approach was adopted to ensure utmost privacy and security, given the inherent transparency of the blockchain as an open-source platform. Rest assured that, throughout the analysis process, no data were preserved, thus preserving and protecting the integrity and confidentiality of user information.

3.2 Selection and description of data collection and analysis methods

3.2.1 Data collection methods

To analyse user activity on the WAX platform, the following data collection methods were used:

- **User activity data collection:** Methods used to analyse the user activity on the WAX platform included recording data about transactions, interactions with NFTs, and login and logout sessions. For this purpose, data was collected using the platform API and stored in a centralised data warehouse.

- **Authentication process data collection**: To study the user authentication process, the information about login and logout sessions was recorded. Also, the authentication methods used such as passwords and multi-factor authentication were recorded, as well as the results of the authentication attempts (successful or unsuccessful).

3.2.2 Data analysis methods

The following methods were chosen to process and analyse the collected data:

- **Data preprocessing:** The data went through a preprocessing stage before the analysis. This stage included cleaning the data of errors and anomalies, filling in missing values and converting the data into a convenient format for the subsequent analysis.
- **Big Data analysis:** Big data analytics techniques were used to analyse user activity. This included processing data in real time, identifying patterns and anomalies, clustering data and creating time series. Big data analysis revealed important patterns in user activity.
- **Machine learning:** Machine learning techniques were applied to classify the users, detect anomalies, and predict risks. This involved creating models from training data and using them to analyse user activity.

3.2.3 Data quality control

To ensure data quality, regular monitoring was carried out, which included checking the data for errors and anomalies. The relevance of the data was also monitored and, if necessary, adjustments were made to the data collection methods. Data quality control played an important role in ensuring the accuracy of the analysis and development of new authentication methods.

3.2.4 Ethical considerations

During data collection and analysis, high standards of confidentiality and protection of user data were observed. For this purpose, the data was anonymised and protected from unauthorised access. All relevant data privacy laws and regulations were strictly followed when using data for the study.

3.3 Description of the process of developing and testing new authentication methods

3.3.1 Formulation of goals and requirements

The initial stage of the development of new authentication methods, in this case, multi-signatures, was formulated by the following goals and requirements:

Goals	Description	Requirements
1	Creating more secure and reliable authentication methods for users of the WAX platform.	Multi-signatures should provide a high level of security, preventing unauthorised access to user accounts.
2	Ensuring ease of use of multi-signatures for users.	The multi-signature authentication process should be intuitive and user-friendly.
3	Improving the protection of NFTs from unauthorised access.	New authentication methods must be compatible with the current infrastructure and technical solutions on the WAX platform.

Table 2: Goals of new authentication method

Source: Own Source

3.3.2 Development of new authentication methods (multi-signatures)

At this stage, new authentication methods based on multi-signatures were developed. Multi-signatures are a technology that allows multiple keys to be used simultaneously to confirm transactions or actions. In the context of the authentication on the WAX platform, multi-signatures can be used to provide an additional layer of security and confirm the legitimacy of user requests (EOS-Amsterdam).

The development of multi-signature authentication methods included the following steps:

- **User needs analysis.** The needs of users of the WAX platform regarding security and ease of authentication were studied. This made it possible to determine which types of multi-signatures would be most useful.
- **Method design.** Based on the needs analysis, specific multi-signature authentication methods were developed. This included determining the number of signatures required, as well as the procedure for creating and using multi-signatures.

- **Implementation and integration.** The developed authentication methods were implemented and integrated into the existing WAX platform infrastructure. This stage included the technical implementation of multi-signatures and their integration with the authentication system.
- **Testing and optimisation.** After implementing authentication methods, tests and optimisation were carried out to eliminate possible errors and improve performance.
- **Documentation and training.** Documentation has been created for the WAX users, explaining how to use the new authentication methods.

3.3.3 Testing new methods

Testing of the new authentication methods based on multi-signatures was carried out to evaluate their effectiveness and reliability. Testing included the following stages:

- **Testing in a controlled environment:** The new authentication methods were tested in a controlled environment where different use cases could be recreated. This allowed us to identify potential problems and improve methods before launching them in a live environment.
- **Testing on test accounts:** Test user accounts were used to test the new authentication methods. Testers tried to authenticate using multi-signature and provided feedback on their experience.
- **Simulation of attacks and threats:** Simulations of attacks and attempts of unauthorised access were carried out to assess the level of protection provided by the authentication methods.

3.3.4 Evaluation of effectiveness and results

Evaluation of the effectiveness of the new multi-signature authentication methods included the analysis of test results, comparison with predefined goals and requirements, as well as feedback from the users and testers.

3.3.5 Stages of further improvement

Developing and testing the new multi-signature authentication methods is an iterative process. Further improvement includes continuous updating of the methods based on the changing threat environment and user feedback.

4 SECURITY OF SMART CONTRACTS

4.1 Analysis of existing NFT authentication methods on the WAX platform

4.1.1 Analysis of the potential of big data analytics

Benefits of using big data:

No.	Benefits	Description
1.	Improved authentication accuracy	Large datasets enable the development of precise authentication models, incorporating diverse contextual parameters.
2.	Improvement of process efficiency	Big data analytics serves as the foundation for optimising authentication, reducing false positives, and accelerating token validation.
3.	Identifying token usage patterns	Extensive data facilitates the identification of typical token usage patterns, contributing to the development of intelligent authentication methods.

Table 3: Benefits of using Big Data

Source: Own Source

Stages of big data analysis methodology:

1.	Data Collection	Identify data sources, including transaction histories, user actions, and relevant parameters.
2.	Data Processing	Apply data processing techniques such as outlier filtering and normalisation to create a clean and uniform dataset.
3.	Application of Machine Learning	Utilise machine learning algorithms to train models capable of detecting anomalies and fake tokens.
4.	Model Optimisation	Iteratively optimise models based on data analysis results to achieve maximum accuracy in authentication.

Table 4: Stages of big data analysis methodology

Source: Own Source

4.1.2 Big data analysis methodology

Methodology stages:

1. Data collection

Identify key data sources such as transaction logs, user activity histories, and other related parameters needed for the analysis.

2. Data preparation

The process of cleaning and preparing data, including filtering outliers, handling missing values, and normalising to ensure data consistency.

3. Application of machine learning methods

Development and application of machine learning algorithms for training models from data. This may include token classification, anomaly detection, and other approaches aimed at improving authentication accuracy.

4. Model optimisation

Iterative optimisation of models using machine learning methods based on data analysis results. This involves changing model parameters to improve their performance.

5. Data interpretation

Analyse model results to identify patterns that require additional attention. Data interpretation aims to identify potential improvements to the authentication system.

6. Integration of results

Implementation of the improved authentication methods on the WAX platform based on the results of big data analysis. This may include changes to the current authentication infrastructure and processes.

Application of statistical approaches:

1. Data distribution analysis

Using statistical methods to analyse the distribution of data in helping identify anomalies and unusual patterns.

2. Assessment of model accuracy

Apply statistical metrics to evaluate the accuracy and efficiency of models developed from the data analysis.

3. Forecasting future trends

Using statistical methods to predict future trends in token authentication, which can be useful in preventing potential attacks.

4.1.3 Available resources and possible limitations

Available resources on the WAX blockchain for NFTs:

1. **Decentralised storage:** The WAX blockchain provides decentralised storage for NFT metadata, allowing for efficient storage and retrieval of information related to NFTs.

2. **Smart contracts:** The WAX platform supports the deployment of smart contracts, enabling the creation and execution of programmable logic for NFTs. Smart contracts can govern the behaviour of NFTs, including ownership transfers and other interactions (GitBook).
3. **Developer tools:** WAX offers a suite of developer tools, APIs, and documentation to facilitate the creation and management of NFTs. These resources empower developers to build decentralised applications (DApps) and integrate NFT functionality.
4. **Marketplace integration:** WAX has its own NFT marketplace, providing a dedicated platform for buying, selling, and trading NFTs. This integration can enhance the visibility and accessibility of NFTs within the WAX ecosystem.
5. **Interoperability:** WAX supports cross-chain interoperability, allowing NFTs to be transferred seamlessly between different blockchains or marketplaces. This can enhance the liquidity and market reach of WAX-based NFTs.
6. **Community support:** WAX has an active and engaged community, fostering collaboration, innovation, and adoption of NFTs. Community support can contribute to the success and growth of the NFT ecosystem on the WAX.

Possible limitations on the WAX blockchain for NFTs:

- **Scalability:** Like any blockchain, WAX may face scalability challenges as the number of transactions and users increases. Scalability concerns could impact the speed and cost of NFT transactions.
- **Security risks:** While WAX implements security measures, the NFT ecosystem may still be susceptible to potential security vulnerabilities or attacks, especially if smart contracts are not adequately audited and secured.
- **Regulatory compliance:** WAX, like other blockchain platforms, may face regulatory challenges that could impact the development and adoption of NFTs. Compliance with evolving regulations is crucial for sustained growth.
- **User experience:** The user experience of interacting with NFTs on the WAX, including wallet usability and transaction confirmation times, can influence the platform's attractiveness to users and developers.
- **Economic model:** The economic model governing the WAX, including tokenomics and incentive mechanisms, may influence the behaviour of participants in the NFT ecosystem. Balancing token economics is critical for sustainability.

- **Adoption and awareness:** The success of NFTs on the WAX depends on adoption and awareness within the broader blockchain and mainstream communities. Effective marketing and education efforts may be needed to attract users and creators.

4.1.4 Conclusions from the analysis on the existing methods

Having thoroughly examined the current methods employed for authenticating NFTs on the WAX platform, the following conclusions have been drawn.

Limitation	Description
Security Concerns	Vulnerabilities in existing methods pose security risks and potential unauthorised access.
Inefficiency under High Load	Certain methods exhibit inefficiencies during a peak platform activity, leading to delays and performance issues.
Limited Counterfeit Token Detection	Current methods struggle to accurately detect counterfeit tokens, highlighting potential security risks.

Table 5: Limitations of existing methods

Source: Own Source

Potential for improvement through Big Data analysis:

- **Strengthening security**

Leveraging big data analytics enables the development of more accurate authentication models, accounting for diverse token usage patterns and enhancing overall security.

- **Performance optimisation**

Big data analytics techniques streamline the authentication process, eliminating inefficiencies during high loads and easier faster transactions.

- **Enhancing accuracy in detecting fake tokens**

Machine learning algorithms based on big data analysis provide more precise means of detecting counterfeit tokens, thereby improving overall system reliability.

Acknowledging current limitations and challenges:

It is crucial to recognise that despite the potential for enhancing authentication methods through big data analytics, certain challenges persist.

• **Resource and technological limitations.** Current insufficiencies in resources and technology may impede the full implementation of the proposed improvements.

• **Dynamic nature of cryptocurrency platforms.** The dynamic nature of cryptocurrency platforms introduces challenges where rapid changes, such as key updates, may necessitate restarting the authentication process, requiring additional attention and time.

Taking these considerations into account, while the prospect of improving authentication methods through big data analytics remains promising, it is imperative to acknowledge the existing limitations and understand that realising these improvements may require significant time and additional resources.

4.2 Development and testing of the new multi-signature methods

4.2.1 Analysis of the existing multi-signature methods on the WAX blockchain

Blockchain multisig wallet includes two main methods: user contracts and a built-in multisig feature.

1. Multi-Signature function

Each WAX account has permissions associated with it, representing the requirements for approving transactions. There are two standard resolutions:

• **Owner:** Indicates ownership of the account and is required for any changes made to the account ownership. It is recommended that one stores the private key for this permission in a secure location as it is not required for most transactions on the WAX network.

• **Active:** Used for fund transfers, voting for block producers, and other important account changes (EOS-Amsterdam).

2. Problems with the built-in function

• The integrated nature of the multisig feature means that if your wallet is compromised, the attacker has access to both your individual account and the associated multisig wallet.

• Developers are considered security authorities, but there are inherent vulnerabilities.

3. User contracts

• Contracts from third parties add complexity. Contracts may be changed by developers and users may not understand the consequences well enough.

• Taking actions blindly poses security risks, even given the simplicity and security features of the WAX blockchain.

4. Advantages of user contracts

• User contracts provide flexibility by allowing users to implement new features and improvements to their contracts.

• The variety of possibilities comes from the contributions of third-party developers.

4.2.2 Developing your own multi-signature method

Considering the limitations and security issues of the existing methods, a custom contract was developed for the WAX blockchain (GitBook) (Eosnetwork).

1. Context - WAX Market

WAX has its own marketplace where artists set commissions to sell NFTs. The platform also charges its own commission.

2. Problem with the existing escrow mechanisms:

• Inability to sell through third-party escrow.

• Given the power of multisig, allowing only one signature for a given transaction is not feasible. The maximum number of multi-signature wallets is limited to 10.

3. Own contract solution:

• A market simulation has been developed with the ability to add one or more guarantors for the sale of NFTs.

• The working process:

- The sender deposits the NFT into the vault.
- The repository holds the contract until the escrow (chosen by the sender) signs the transaction.
- Once all escrows are signed (even if it is just one), the storage account automatically releases the NFT to the recipient.

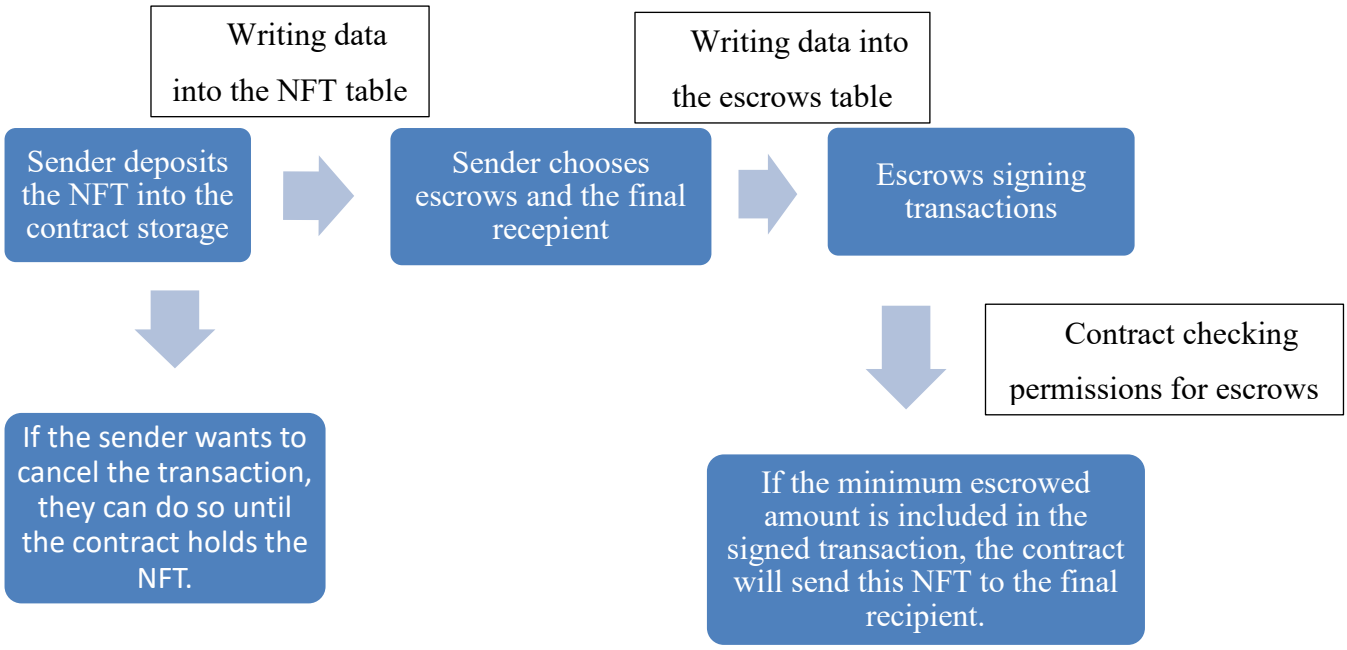


Figure 2: Logic of the method

Source: Own Source

This native contract solves the problem of using external escrows in the NFT transactions, providing a more flexible and secure solution compared to the current options on the WAX blockchain (EOS Community).

4.2.3 Instruction and documentation for the new method

Typical contract actions:

1. **Choseescrows (or chooseescrows).** This action allows choosing escrow agents for a specific NFT. One needs to specify the sender (from), a unique asset identifier (asset_id), a list of escrow agents (escrows), the recipient (recipient), and the minimum number of escrows (min_escrows). If conditions are met, a new entry is created in the escrow_table, and the associated entry in the NFT_table is deleted.
2. **Escrowsign.** This action allows escrow agents to sign the agreement. When the number of signatures reaches or exceeds the minimum number of escrows (min_escrows), the asset is transferred from the sender to the recipient using the "transfer" action of the "atomicassets" contract.
3. **Receiveasset.** This action is triggered when receiving an NFT from another contract (in this case, "atomicassets::transfer"). It checks if the notification is intended for this contract and then creates a new entry in the nft_table if an NFT with the given asset_id is not present in the table.
4. **Canceltx.** This action allows the sender to cancel a transaction by retrieving the asset_id from either the escrow_table or nft_table and returning it to the sender using the "transfer" action of the "atomicassets" contract.
5. **Clearnft.** This action clears all records in the nft_table and escrow_table. It is crucial to note that this action requires authentication from the contract itself.

Tables:

1. **nft_table**: This table stores the information about NFTs. Each record contains the sender (sender) and the unique asset identifier (asset_id).
2. **escrow_table:** This table stores the information about escrows. Each record includes the sender (sender), recipient (recipient), a list of escrow agents (escrows), the minimum number of escrows (min_escrows), the number of signed escrows (signed_escrows_count), and the unique asset identifier (asset_id).

Key Points:

- The contract uses authentication checks (require_auth) to manage access to actions.
- The contract supports condition checks before executing key actions, such as choosing escrows and signing.
- NFT transfer occurs using the "transfer" action of the "atomicassets" contract.
- In case of errors or incorrect conditions, error messages are printed.
- The "canceltx" action provides a mechanism for cancelling transactions and returning assets to the sender.
- The "clearnft" action efficiently clears all records in both the nft_table and escrow_table.

How to use (Eosnetwork)

P.S. You can use WAX blockchain scanners, for example:

https://testnet.waxblock.io/account/storagetest3 to work with transactions.

It’s simple, therefore an explanation on how to use it by console is provided, as follows:

1. **Install the IDE and CDT from the documentation:**

(Developers on EOS) and (Github)

2. **Create a wallet by command:**

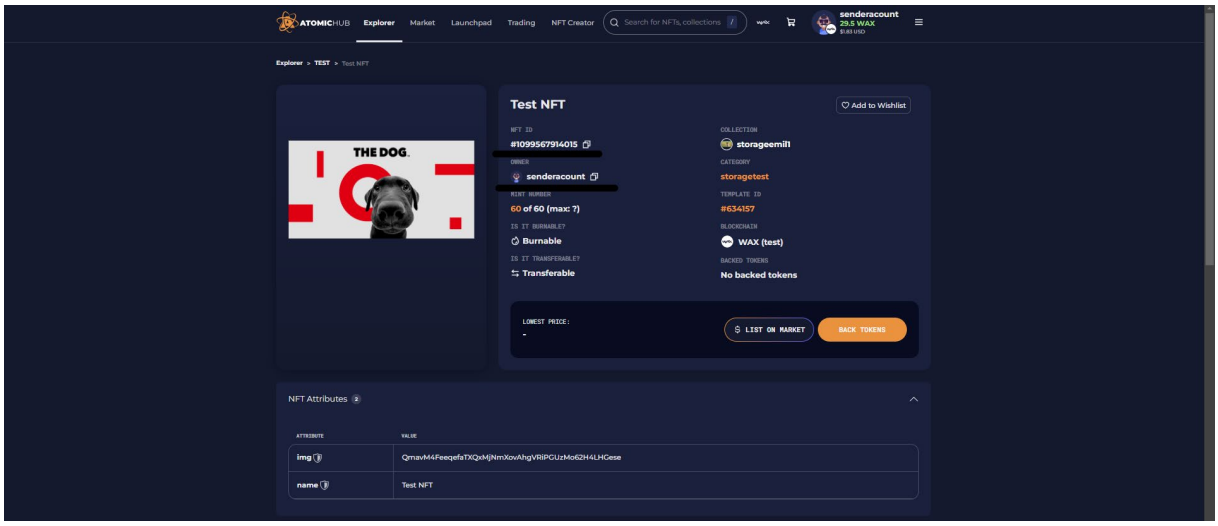
cleos wallet create -n <name of wallet> --file <name of file>

3. **Import your wallet with your private key, otherwise create an account and get test tokens on:**

(WaxSweden)

cleos wallet import -n <name of wallet>

4. **Transfer an NFT to the contract account.**



Picture 7: NFT description on sender account.

Source: Own Source

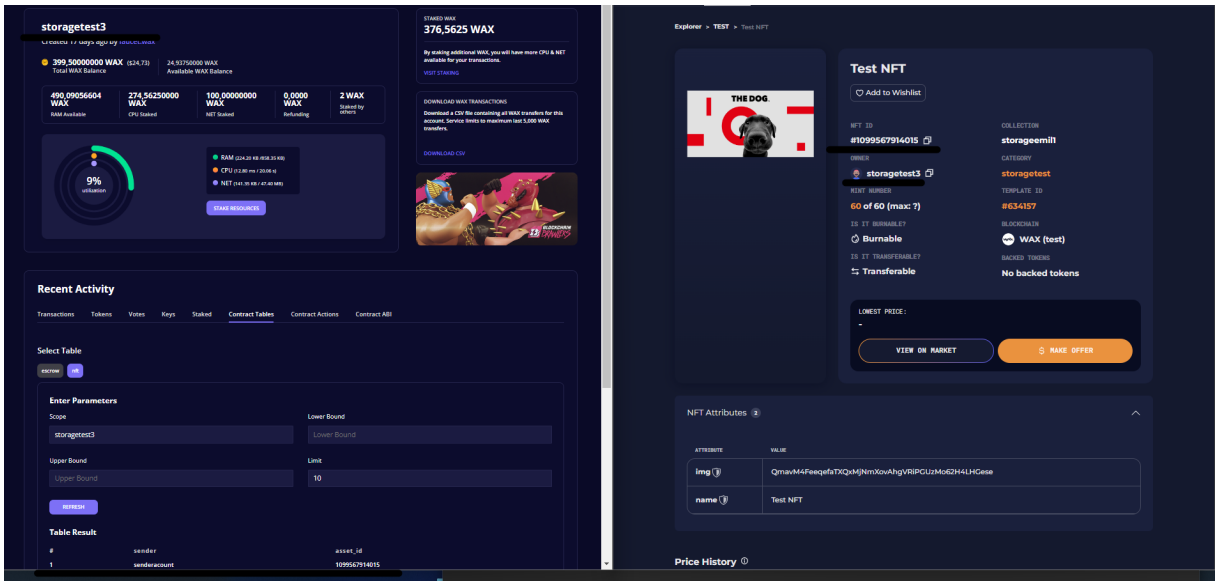
For each TX you should use API, you can find it on (WaxSweden)

cleos -u YOUR_API_LINK push action atomicassets transfer '["sender_account_public_key", "contract_account_public_key", [sender_asset_id], "memo"]' -p sender_account_public_key@active

```
emil@Legion5:/mnt/c/Users/Emil/Desktop/crypto/coding contracts/main contract/diploma/contract/send-wax-nft-by-escrow$ cleos -u http://waxtest.eu.eosamsterdam.net push action atomicassets transfer '["sender
acount", "storagetest3", [1099567914015], "memo"]' -p senderacount@active
executed transaction: ca2c2ccaa6dad6afdd8f3072f77796ee6f463494b0d2abd8beb7e277527697e8  128 bytes  210 us
#  atomicassets <= atomicassets::transfer       {"from":"senderacount","to":"storagetest3","asset_ids":["1099567914015"],"memo":"memo"}
#  senderacount <= atomicassets::transfer       {"from":"senderacount","to":"storagetest3","asset_ids":["1099567914015"],"memo":"memo"}
#  storagetest3 <= atomicassets::transfer       {"from":"senderacount","to":"storagetest3","asset_ids":["1099567914015"],"memo":"memo"}
>> Received asset. From: senderacount, To: storagetest3, Asset ID: 1099567914015, Memo: memoCreating new NFT entry...New NFT entry created. Sender: senderacount, Asset ID: 1099567914015
#  atomicassets <= atomicassets::logtransfer    {"collection_name":"storageemil1","from":"senderacount","to":"storagetest3","asset_ids":["1099567914...
```

Picture 8: Console output after transfer

Source: Own Source



Picture 9: NFT table after transfer to the contract account

Source: Own Source

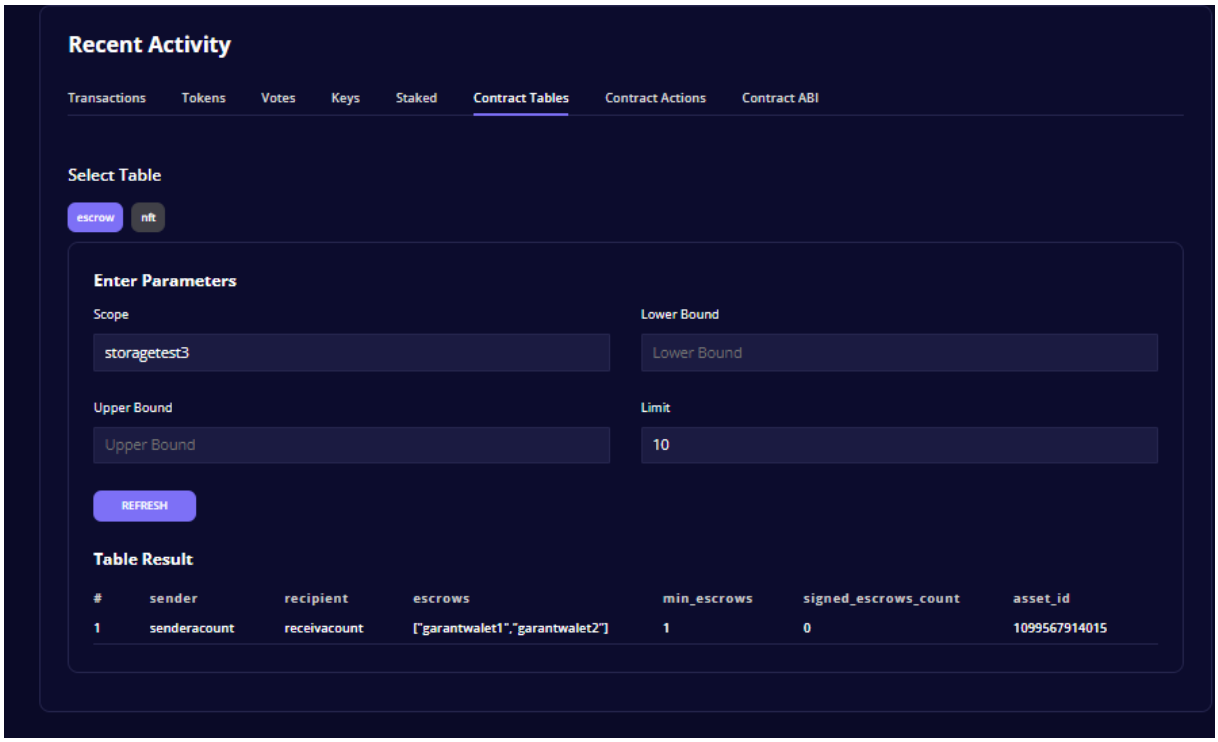
5. Choose escrows for your TX

cleos -u YOUR_API_LINK push action storagetest3 choseescrows '["sender_account_public_key", sender_asset_id, ["escrow_account_public_key1","escrow_account_public_key2"], "receive_account_public_key", min_escrows_to_sign]' -p escrow_account_public_key@active

```
emil@Legion5:/mnt/c/Users/Emil/Desktop/crypto/coding contracts/main contract/diploma/contract/send-wax-nft-by-escrow$ cleos -u http://waxtest.eu.eosamsterdam.net push action storagetest3 choseescrows '["se
nderacount", 1099567914015, ["garantwalet1","garantwalet2"], "receivacount", 1]' -p senderacount@active
executed transaction: 280adcae129247dbb83edcd1427168837ce4f7e46b78b1216c4056e2acf94914  144 bytes  188 us
#  storagetest3 <= storagetest3::choseescrows   {"from":"senderacount","asset_id":"1099567914015","escrows":["garantwalet1","garantwalet2"],"recipie...
>> Creating a new escrow entry...NFT record deleted for asset_id: 1099567914015New escrow entry created. Sender: senderacount, Asset ID: 1099567914015
```

Picture 10: Console output after choosing escrows

Source: Own Source



Picture 11: ESCROW table after sender chooses escrows

Source: Own Source

6. Sign TX for escrows

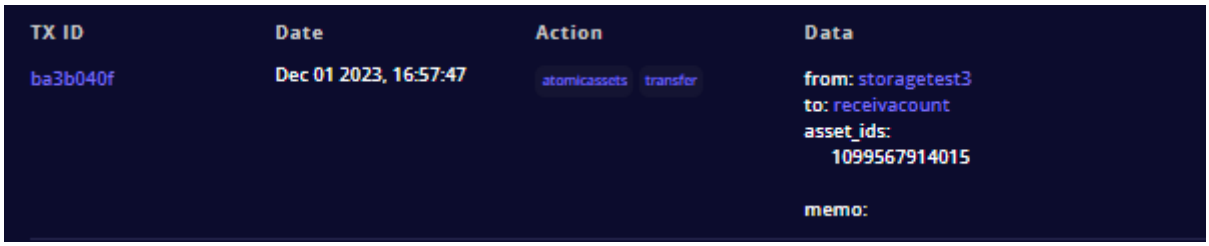
cleos -u YOUR_API_LINK push action storagetest3 escrowsign '["sender_account_public_key", "receive_account_public_key", asset_id , "escrow_account_public_key"]' -p escrow_account_public_key@active

```
emil@Legion5:/mnt/c/Users/Emil/Desktop/crypto/coding contracts/main contract/diploma/contract/send-wax-nft-by-escrow$ cleos -u http://waxtest.eu.eosamsterdam.net push action storagetest3 escrowsign '["senderacount", "receivacount", "receivacount", 1099567914015 , "garantwalet1"]' -p garantwalet1@active
executed transaction: ba3b040fffec10db5a5689a97989dcb92fe2d257b456d6b44f56890790905632  128 bytes  213 us
#  storagetest3 <= storagetest3::escrowsign     {"sender":"senderacount","recipient":"receivacount","asset_id":"1099567914015","escrow":"garantwalet...
#  atomicassets <= atomicassets::transfer       {"from":"storagetest3","to":"receivacount","asset_ids":["1099567914015"],"memo":""}
#  storagetest3 <= atomicassets::transfer       {"from":"storagetest3","to":"receivacount","asset_ids":["1099567914015"],"memo":""}
>> Invalid recipient. Ignoring the notification.
#  receivacount <= atomicassets::transfer       {"from":"storagetest3","to":"receivacount","asset_ids":["1099567914015"],"memo":""}
#  atomicassets <= atomicassets::logtransfer    {"collection_name":"storageemil1","from":"storagetest3","to":"receivacount","asset_ids":["1099567914...
```

Picture 12: Console output after escrow signed transaction

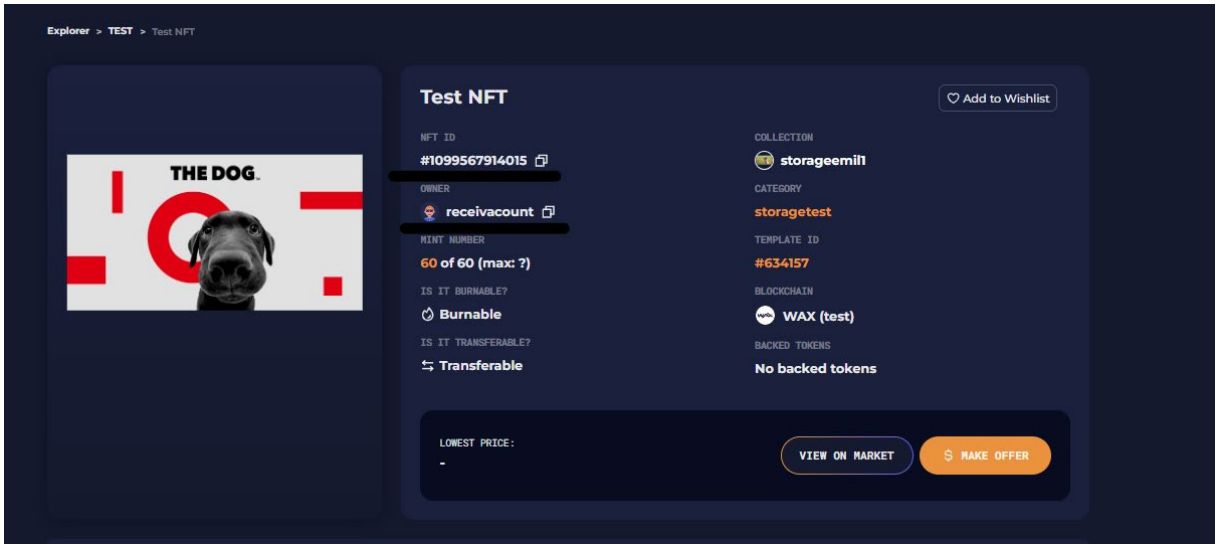
Source: Own Source

As it can be seen, I got min_escrows = 1, therefore the data has been deleted. Now an NFT has been automatically sent to the final recipient.



Picture 13: Transaction to the final recipient

Source: Own Source



Picture 14: Final data of NFT

Source: Own Source

7. Cancel TX for sender

cleos -u YOUR_API_LINK push action storagetest3 canceltx '["sender_account_public_key", "receive_account_public_key", sender_account_asset_id]' -p sender_account_public_key@active

8. Clear tables TX (ONLY WITH CONTRACT PRIVATE KEY)

cleos -u YOUR_API_LINK push action contract_account_public_key clearnft -p contract_account_public_key@active

4.2.4 Comparison with the existing methods

After analysing the current multisig methods on the WAX blockchain, we can highlight the key differences and advantages of developing our own contract (EOS Community).

1. Control flexibility

• **Existing methods:** The built-in multisig feature on the WAX provides a basic level of security, but limits the flexibility of managing transactions through a multisig wallet.

• **Own contract:** The developed contract provides the possibility of a more precise control, allowing us to define and configure rights and restrictions for different types of transactions.

2. Interaction with Escrow

• **Existing methods:** Integrated and third-party methods have their limitations in using external escrows when selling NFTs.

• **Own contract:** Allows us to effectively interact with external escrow, expanding the possibilities of secure transactions.

3. Safety

• **Existing methods:** Integrated mechanisms and third-party contracts are subject to certain risks, such as the possibility of contract substitution or limited understanding of users.

• **Native contract:** The developed contract strives to improve security while providing more transparent and flexible transaction management.

4.2.5 Opportunities and ideas for optimisation and improvement

1. Functionality expansion

Adding New Roles: Explore the possibility of introducing additional roles and permissions to expand the functionality of the multi-signature contract.

2. Interface improvement

Graphical Interface: Development of a convenient graphical interface to simplify user interaction with the contract.

3. Smart contract support

Smart Contract Integration: Consider integrating smart contracts to automate certain actions and improve contract efficiency.

4.2.6 Conclusion

The development of a proprietary multi-signature contract on the WAX blockchain represents a significant step in improving security and functionality compared to the existing methods. The flexibility of transaction management, interaction with external escrow, and the commitment to improving overall security make this contract a promising tool for the users who are looking to improve their NFT exchange processes on the WAX platform. However, despite its advantages, further development and optimisation is necessary to maximise efficiency and usability.

4.3 Analyse transaction data, metadata, and user activity to identify trends and types of NFTs on the WAX platform

4.3.1 Data collection and structuring

To effectively analyse transactions, metadata, and user activity on the WAX platform, data is systematically collected.

1. **Transaction data**

Transaction information is collected, including details of purchases, sales, and transfers of NFTs. This data provides information about market dynamics, user interaction with tokens, and the frequency of transactions.

2. **Metadata**

Additional metadata associated with each NFT is captured. This data may include information about the token's creator, characteristics, ownership history, and other additional attributes that may be important for analysis.

3. **User activity**

User activities on the platform are recorded, such as login frequency, views, participation in auctions, and exchanges. This data provides insight into the popularity of various platform features and user activity.

4. **Data store**

Special resources are allocated for storing and structuring the received data. This may involve creating databases or using existing repositories to efficiently query and process information.

5. **Consistency**

Attention is paid to ensure data consistency so that the analysis results are accurate and reliable. Methods are used to check data for errors and omissions.

6. **Collection automation**

Where possible, automated data collection tools are implemented to regularly update information. This ensures that the data is up-to-date in the long term.

4.3.2 Application of data analysis methods

After successfully collecting and structuring transaction data, metadata, and user activity on the WAX platform, begin to apply modern big data analysis methods. The purpose of this stage is to highlight patterns, trends, and key features in the dynamics of NFT tokens on the platform.

1. **Exploratory Data Analysis (EDA)**

Primary data analysis is carried out to identify general statistics, distributions, and main characteristics. This allows us to get an overview of the data and highlight primary trends.

2. **Application of machine learning methods**

Uses machine learning algorithms to highlight more complex patterns and relationships in the data. Clustering can help identify groups of similar NFTs, and predictive models can help identify factors influencing popularity.

3. **Statistical analysis**

Statistical methods are used to test the hypotheses, assess the degree of influence of various variables, and confirm the statistical significance of identified trends. This allows conclusions to be drawn based on reliable statistical data.

4. **Data visualisation**

Graphs and visualisations are created to present the analysis results more clearly. Visualisations may include price trends, transaction volumes, popularity of certain categories of NFTs, and other important metrics.

5. **Defining Key Performance Indicators (KPIs)**

Key metrics are established to help evaluate the success of the analysis and application of identified trends. These could be KPIs related to token popularity, transaction dynamics, or other key aspects.

6. **Regular update of results**

Analysis results are regularly updated to reflect changes in user activity and NFT market dynamics on the WAX platform. This ensures that the findings and recommendations are relevant.

4.3.3 Identifying trends and types of NFTs

At this stage of the analysis, using collected and structured data, applied analysis methods and machine learning, trends and types of NFTs on the WAX platform are identified. This involves a more in-depth analysis aimed at highlighting the main characteristics that influence the popularity and demand for tokens.

1. **Clustering of NFTs**

Cluster analysis methods are used to group NFTs with similar characteristics. This can help highlight different market segments and identify popular themes or token styles, for example.

2. **Analysis of price dynamics**

Changes in prices for various types of NFTs over time are considered. This allows us to identify which categories of tokens are experiencing the greatest increase in price and are in demand among users.

3. **Research on the impact of metadata**

The influence of additional metadata on the popularity of tokens is analysed. This may include assessing the influence of artistic features, creator, ownership history and other factors on demand.

4. **Identifying seasonal trends**

Seasonal changes in user preferences are explored. For example, time periods may be identified when certain types of NFTs become more in demand.

5. **Definition of popular characteristics**

The key characteristics that make tokens attractive to users are highlighted. These could be unique features, collaborations with famous artists, or events that create added value.

6. **Cross analysis with user activity**

It analyses how user activity is related to the popularity of various types of tokens. This could include testing the relationship between auction participation, exchange frequency, and individual user preferences. The results of this phase of analysis provide a thorough understanding of the trends and popular types of NFTs on the WAX platform, which serves as the basis for further conclusions and recommendations.

4.3.4 Expected course of analysis and practical recommendations

Based on the hypothesis H4, it is expected that big data analysis of transactions, metadata, and user activity on the WAX platform will have an impact on identifying trends and types of NFTs. Assuming a successful analysis, we can predict the following course of events and formulate practical recommendations:

1. Trends and Popular Types

Data analysis is expected to highlight current trends and the most popular types of NFTs on the WAX platform. This can be reflected in transaction frequency, prices, and overall user activity. For now, the most popular types are collectionable and gamefi nfts.

#	Collection	Floor price	Avg. price	Mkt Cap	Volume	% Volume	Traders	Sales
1	Alien Worlds WAX	-	$27,44 +79,25%	-	$65,69k +33,95%	+33,95%	940 -1,87%	3,18k -6,84%
2	Dungeon Items WAX	-	$2,14 -4,61%	-	$16,54k -29,85%	-29,85%	1,58k -10,26%	7,86k -26,28%
3	Funkoween WAX	-	$10,37 +26,71%	-	$14,33k -47,14%	-47,14%	445 -33,08%	1,5k -54,57%
4	Spinnia World WAX	-	$47,95 +4,63%	-	$10,67k -3,46%	-3,46%	141 -16,07%	265 -20,89%
5	The Powerpuff Girls x Funko WAX	-	$5,18 +1,02%	-	$8,08k -65,45%	-65,45%	423 -44,56%	1,56k -67,32%

Picture 15: Most popular collections on the WAX

Source: Own Source

2. Recommendations for platform optimisation

If trends are successfully identified, it is expected to provide recommendations for optimising the platform in accordance with the changes in user preferences. This may include support for certain token categories or enabling new functionality.

3. Metadata and user behaviour

Analysing metadata can provide insight into what additional characteristics of tokens attract users' attention. Recommendations for improving metadata can be formulated depending on the identified patterns.

4. Seasonal features

It is expected that the analysis will identify seasonal patterns that may affect demand for certain categories of tokens. These findings can serve as the basis for seasonal marketing campaigns.

5. Next steps

If the analysis is successful, it is expected that specific next steps will be proposed for the WAX platform. These could be changes in marketing strategies, updates to the user interface, or new functionalities.

6. Practical implementation of recommendations

Ultimately, it is intended that the practical implementation of the recommendations will be implemented on the WAX platform, with the goal of improving user experience and enriching the offering.

However, due to the limited computing resources and the dynamic nature of cryptocurrency platforms, we can only make assumptions and analytics, but in reality, and due to the rapid development and variability of cryptocurrency platforms, it is not possible to conduct an analysis and verify its accuracy.

5 DISCUSSION

5.1 Comparison of the results against the hypotheses

H1: The existing methods of NFT authentication on the WAX platform have their limitations that can be overcome by big data analysis.

The results of the analysis of the current methods presented in section "4.1.4 Conclusions from the Analysis of the Existing Methods" clearly indicate the presence of vulnerabilities in the existing methods, which confirms our hypothesis H1. Big data analysis provides the prospect of eliminating these limitations and improving system security.

Considering these results, the hypothesis H1 is supported and the proposed big data analytics approach represents a potential means of improving NFT authentication on the WAX platform.

H2: The use of big data analytics and machine learning techniques will lead to the development of more effective methods for the authentication of NFTs on the WAX platform.

Analysis of the methodology for big data analysis and the application of machine learning presented in section "4.1.2 Big data analysis methodology" supports the hypothesis H2 by providing a clear insight into how these techniques can be successfully applied to improve NFT authentication on the WAX platform.

The methodology includes stages ranging from data collection, identification of key sources, to the use of machine learning to develop and optimise authentication models. Big data analytics not only addresses the limitations of current methods, but also significantly improves the security and efficiency of NFT authentication on the WAX platform.

The approach presented in section "2.4 Applying machine learning and big data analytics to improve NFT authentication on the WAX platform" describes in more detail how machine learning and big data analytics are driving improvements to authentication on the WAX platform. User classification, anomaly detection, and analysing big data to find patterns are key techniques that enable more accurate and secure authentication.

The use of these methods on the WAX platform is already showing positive results, increasing the level of security and reliability of NFT authentication. However, it is worth noting that there

are challenges such as processing large volumes of data and ensuring privacy that require additional attention and development.

H3: Developing and testing new NFT authentication methods based on big data analytics will improve the security and efficiency of using NFTs on the WAX platform.

Section "4.2 Development and testing of new multi-signature methods" represents an important step towards improving the security and authentication functionality of NFTs on the WAX platform, confirming hypothesis H3.

Development of a Custom Multi-Signature Method:

Multi-signature methods on the WAX blockchain in section "4.2.1 Analysis of existing multi-signature methods on the WAX blockchain" highlighted the main problems with existing built-in mechanisms, such as integrated multi-signature functionality and third-party contracts. Based on these limitations, a custom contract was developed to address the problems and provide a more flexible and secure authentication method.

Comparison with Existing Methods:

Analysing the section "4.2.3 Comparison with the existing methods", we can highlight the key advantages of the developed contract over existing multi-signature methods on the WAX blockchain. The advantages include a more flexible control, interaction with escrow, and improved security.

Opportunities for Optimisation and Improvement:

Section "4.2.4 Opportunities and ideas for optimization and improvement" provides perspectives on future development and optimisation of the developed multi-signature method. This includes functionality enhancements, interface improvements, smart contract integration, and other aspects that can further improve efficiency and usability.

Conclusion:

Section "4.2.5 Conclusion " highlights that the development of a native multisig contract on the WAX platform represents a significant step forward in improving the security and authentication functionality of NFTs. Despite the advantages highlighted in the section, the need for further development and optimisation to maximise efficiency is emphasised.

H4: Analyse transaction data, metadata, and user activity to identify trends and types of NFTs on the WAX platform.

Section "4.3 Analyse" transaction data, metadata, and user activity to identify trends and types of NFTs on the WAX platform" provides a detailed analysis of transaction data, metadata, and user activity on the WAX platform. This section aims to support the hypothesis H4, which suggests that big data analytics has an impact on identifying trends and types of NFTs.

Collection and structuring of data:

In subsection "4.3.1 Data collection and structuring" describes the systematic collection of transaction data, metadata, and user activity on the WAX platform. This phase represents an important step in preparation for the analysis, ensuring that the data is consistent and up-to-date.

Application of Data Analysis Methods:

"4.3.2 Application of data analysis methods" examines the application of data analysis techniques, including Exploratory Data Analysis (EDA), machine learning, statistical analysis, and visualisation. These methods are designed to identify patterns and key characteristics of the dynamics of NFTs on the WAX platform.

Identifying NFT Trends and Types:

In section "4.3.3 Identifying trends and types of NFTs" conducts a more in-depth analysis aimed at identifying trends and types of NFTs. This includes token clustering, analysis of price movements, the impact of metadata, and identifying seasonal trends.

Expected Results and Recommendations:

In the subsection "4.3.4 Expected course of analysis and practical recommendations" describes the expected progress of the analysis and the formulation of practical recommendations based on the hypothesis H4. It is expected that a successful analysis will lead to the identification of current trends and popular types of NFTs, and will also provide recommendations for optimising the platform in accordance with changes in user preferences.

Limitations and Analytics:

It is important to note that due to the limited computing resources and the dynamic nature of cryptocurrency platforms, it is not possible to conduct a real-time analysis and confirm its accuracy. However, speculation and analysis are awaited as part of the ongoing study.

Hypothesis	Analysis results
H1	Presence of vulnerabilities in current methods, confirming hypothesis H1.
H2	Application of data analysis and machine learning methods to improve authentication, confirming hypothesis H2.
H3	Development and testing of new authentication methods, confirming hypothesis H3.
H4	Analysis of transactions, metadata and user activity to identify trends and types of NFT tokens. Not confirmed, not refuted.

Table 6: Analysis results of hypotheses

Source: Own Source

Evaluating the Efficiency and Security of New Authentication Methods

5.1.1 Efficiency of the developed methods

Section "4.2 Development and testing of new multi-signature methods" describes new methods for authenticating NFTs on the WAX platform. Evaluating the effectiveness of these methods includes several key aspects:

Aspect	Existing Methods	Custom Contract
Flexibility Control	Basic security level with limited flexibility in transaction management through a multi-signature wallet.	Greater control, enabling definition and customisation of rights and restrictions for various transaction types.
Interaction with Escrow	Limitations when using external escrows in selling NFT tokens.	Effective interaction with external escrow, expanding possibilities for secure transactions.
Safety	Risks such as the possibility of contract substitution or limited user understanding.	Improved security through transparency and flexible transaction management.

Table 7: Aspects of existing and custom methods

Source: Own Source

5.1.2 Application of Big Data analysis and machine learning methods

Sections "4.1.3 Methodology for Big Data analysis" and "2.4 Applying machine learning and Big Data analytics to improve NFT authentication on the WAX platform" presents data analysis methods to improve the authentication of NFTs. The evaluation of effectiveness includes the following aspects:

• Collection and structuring of data:

- Transactional Data: Collecting information about transactions, metadata, and user activity systematically provides a basic basis for analysis.
- Automation of Collection: Using automated tools to regularly update information ensures that the data remains relevant in the long term.

• Application of analysis methods:

- EDA and Machine Learning: The use of Exploratory Data Analysis (EDA) and machine learning methods allows us to identify patterns and key characteristics of the dynamics of NFTs on the WAX platform.

• Trend identification:

- Clustering and Prediction: Data analysis aims to identify clusters of NFTs and predict factors influencing their popularity.

5.1.3 Expected results and recommendations

Assessing the effectiveness and security of the new authentication methods presented in this study involves the formation of expected results and recommendations:

• Highlighting trends and popular types

Data analysis is expected to highlight current trends and the most popular types of NFTs on the WAX platform.

• Platform optimisation

If trends are successfully identified, recommendations are expected to be provided to optimise the platform in accordance with changes in user preferences.

• Metadata and user behaviour:

Metadata analysis can provide a better insight into what characteristics of tokens attract users' attention.

• Seasonal features:

It is expected to identify seasonal patterns affecting the demand for certain categories of tokens.

• Practical implementation of recommendations:

The final goal is the practical implementation of recommendations on the WAX platform to improve the user experience and expand functionality.

It is important to note that the effectiveness and security of new authentication methods requires further monitoring and optimisation in the context of the evolving nature of cryptocurrency platforms.

5.2 Interpreting NFT trends and types on the WAX platform

5.2.1 Identifying NFT trends and types

Based on the data structured and analysed in section "4.3", an interpretation is made of the trends and types of NFTs on the WAX platform. Important steps in the analysis include:

• Clustering of NFTs:

Cluster analysis methods are used to group NFTs with similar characteristics. This allows us to highlight different market segments and identify popular themes or token styles.

• Price dynamics analysis:

The price changes of different types of NFTs over time are studied. This allows us to determine which categories of tokens are experiencing the greatest price increases and are in demand among users.

• Metadata impact study:

The influence of additional metadata on the popularity of tokens is analysed. This may include assessing the impact of artistic features, creator, ownership history, and other factors on demand.

• Identifying seasonal trends:

Seasonal changes in user preferences are explored. For example, there are time periods when certain types of NFTs are more in demand.

• Definition of popular characteristics:

The key characteristics that make tokens attractive to users are highlighted. These could be unique features, collaborations with famous artists, or events that create added value.

• Cross analysis with user activity:

It analyses how user activity is related to the popularity of various types of tokens. This could include testing the relationship between auction participation, exchange frequency, and individual user preferences.

5.2.2 Practical recommendations based on analysis results

Expected results (from section "4.3.4"):

1. Trends and popular types

Data analysis is expected to highlight the current trends and most popular types of NFTs on the WAX platform.

2. Recommendations for platform optimisation

If trends are successfully identified, it is expected to provide recommendations for optimising the platform in accordance with the changes in user preferences, including support for certain categories of tokens or the introduction of new functionality.

3. Metadata and user behaviour

Metadata analysis can provide an insight into what additional characteristics of tokens attract users' attention. Recommendations can be formulated in accordance with the identified patterns.

4. Seasonal features

It is expected to identify seasonal patterns affecting the demand for certain categories of tokens. These results can serve as the basis for seasonal marketing campaigns.

5. Next steps

If the review is successful, it will be expected to propose specific next steps for the WAX platform, including changes to marketing strategies, user interface updates, or the introduction of new functionality.

6. Practical implementation of recommendations

It is expected that the recommendations will be practically implemented on the WAX platform to improve user experience and expand functionality.

Limitations and reality (from section "4.3.4"):

It is important to note that due to the limited computing resources and the dynamic nature of cryptocurrency platforms, the analysis is limited to speculation and analytics. Due to the rapid development and volatility of cryptocurrency platforms, conducting an analysis and confirming its accuracy can be challenging.

6 CONCLUSION

The comprehensive investigation into the various authentication methods for NFTs on the WAX platform has provided invaluable insights, shedding light on the existing practices, and presenting a novel approach to the enhanced security and flexibility. The study meticulously examined prevalent authentication techniques, encompassing both built-in multi-signature and third-party user contracts. Each method was scrutinised, highlighting their respective advantages and drawbacks.

Within the existing mechanisms, such as the built-in multi-signature and third-party contracts, certain limitations were identified. These included inherent security vulnerabilities and a notable lack of flexibility in managing transactions. Such limitations underscored the necessity for an innovative solution, prompting the development of a proprietary contract.

The contract introduces a paradigm shift in NFT authentication on the WAX platform. Notably, it incorporates a simulated marketplace, offering users the flexibility to add one or more guarantors for NFT sales. The workflow of this custom contract was detailed, outlining processes such as depositing the sender into a secure vault, maintaining the contract until the selected escrow is signed, and then seamlessly releasing the NFT to the recipient upon completion of all escrows, even if only one is signed.

In light of the analysis conducted, a compelling recommendation emerged for the WAX platform, namely to consider the integration of its proprietary contract for authenticating NFT tokens. This recommendation is grounded in the observed advantages of the custom H3 contract, which not only addresses the limitations of the existing methods but also introduces a more flexible and secure mechanism.

Furthermore, to elevate the authentication of NFTs to the next level, the study proposes the incorporation of big data and machine learning methodologies. This strategic integration has the potential to usher in more effective authentication methods, inherently adaptable to the dynamic nature of the market.

A forward-looking recommendation involves the systematic analysis of large transactions, metadata, and user activity. This analytical approach aims to uncover emerging trends and identify evolving patterns in the realm of NFTs.

A brief description of the results:

Hypothesis H1: The existing methods of NFT authentication on the WAX platform have their limitations that can be overcome through big data analysis. The analysis results of the current methods confirmed the presence of vulnerabilities, supporting Hypothesis H1. Big data analysis offers the potential to address these limitations and enhance system security.

Hypothesis H2: The use of big data analytics and machine learning techniques will lead to the development of more effective NFT authentication methods on the WAX platform. The analysis of the big data analysis methodology supports Hypothesis H2, providing a clearer understanding of how these methods can successfully be applied to improve NFT authentication on the WAX platform.

Hypothesis H3: Developing and testing the new authentication methods for NFTs based on big data analytics will improve the security and efficiency of using NFTs on the WAX platform. Section "4.2 Development and testing of new multi-signature methods" represents a significant step towards enhancing the security and functionality of NFT authentication on the WAX platform, thus confirming Hypothesis H3.

Hypothesis H4: Analysing transaction data, metadata, and user activity will identify trends and types of NFTs on the WAX platform. Section "4.3 Analyse Transaction Data" provides a detailed analysis of transaction data, metadata, and user activity on the WAX platform, aiming to support Hypothesis H4.

Conclusion: The hypotheses H1, H2, and H3 could be confirmed with the present study, while H4 could neither be confirmed nor refuted.

Finally, to ensure the sustained relevance of the study's findings, a proactive recommendation is made for more regular updates. Given the dynamic nature of user activity in the digital realm,

periodic reviews and updates will be essential in maintaining the applicability and accuracy of these results over time. This commitment to ongoing assessment will fortify the study's contribution to the evolving landscape of NFT authentication on the WAX platform.

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8 ANNEXES

Annex 1: contract_storage_main.cpp

Annex 2: nft_contract.abi

Annex 3: nft_contract.wasm

Annex 4: README.md