**Detailed Literature Review – Part 1**

**What are smart contracts?**

**(From Paper [2])**

Smart contracts can be regarded as a great advance in blockchain technology [29]. In 1990s, a smart contract was proposed as a computerized transaction protocol that executes the contractual terms of an agreement [1]. Contractual clauses that are embedded in smart contracts will be enforced automatically when a certain condition is satisfied (e.g., one party who breaches the contract will be punished automatically).

Blockchains are enabling smart contracts. Smart contracts are essentially implemented on top of blockchains. The approved contractual clauses are converted into executable computer programs. The logical connections between contractual clauses have also been preserved in the form of logical flows in programs (e.g., the if-else-if statement). The execution of each contract statement is recorded as an immutable transaction stored in the blockchain. Smart contracts guarantee appropriate access control and contract enforcement. In particular, developers can assign access permission for each function in the contract. Once any condition in a smart contract is satisfied, the triggered statement will automatically execute the corresponding function in a predictable manner. For example, Alice and Bob agree on the penalty of violating the contract. If Bob breaches the contract, the corresponding penalty (as specified in the contract) will be automatically paid (deducted) from Bob’s deposit.

The whole life cycle of smart contracts consists of four consecutive phases as illustrated in Figure 3: 1) Creation of smart contracts. Several involved parties first negotiate on the obligations, rights and prohibitions on contracts. After multiple rounds of discussions and negotiations, an agreement can reach. Lawyers or counselors will help parties to draft an initial contractual agreement. Software engineers then convert this agreement written in natural languages into a smart contract written in computer languages including declarative languages and logic-based rule languages [30]. Similar to the development of computer software, the procedure of the smart contract conversion is composed of design, implementation and validation (i.e., testing). It is worth mentioning that the creation of smart contracts is an iterative process involving with multiple rounds of negotiations and iterations. Meanwhile, it is also involved with multiple parties, such as stakeholders, lawyers and software engineers.

The whole life cycle of smart contracts consists of four consecutive phases as illustrated in below figure [2]

A diagram of blockchain process

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The functioning of a blockchain-based smart contract is briefly discussed in [41]. The steps involved in the working of smart contracts can be summarized as follows:

**(From Paper [5])**

**1) Creation:** Several involved parties first negotiate on the obligations, rights and prohibitions on contracts. After multiple rounds of discussions and negotiations, an agreement can reach. Similar to the

development of computer software, the procedure of the smart contract conversion is composed of design,

implementation and validation (i.e., testing). It is worth mentioning that the creation of smart contracts is an iterative process involving with multiple rounds of negotiations and iterations. Meanwhile, it is also involved with multiple parties, such as stakeholders, lawyers and software engineers [2].

**2) Deployment:** The smart contract is then deployed to the blockchain network. This step involves paying the network a fee, known as gas, to execute the contract **[5]**.

**3) Execution:** The smart contract is now live on the blockchain and can execute automatically when certain conditions are met. These conditions are programmed into the contract and are triggered by specific actions or events. As the smart contract executes, each step is verified by the nodes on the blockchain network. This ensures the contract is executed correctly and the terms are upheld. **[5]**

**4) Completion:** Once the smart contract conditions are met, the contract automatically executes, and the out- come is recorded on the blockchain. This outcome can be anything from the transfer of funds to the delivery of goods. **[5]**

**What are NFT based smart contracts, and their applications, advantages and disadvantages (with citations)**

**(From Paper [5])**

Non-fungible tokens (NFTs) are digital assets with distinct characteristics, setting them apart from other digital assets like cryptocurrencies or traditional financial instruments [5]. Unlike cryptocurrencies, NFTs are not interchangeable with one another, and each NFT is unique, representing a specific item or asset. On the other hand, fungible items are interchangeable because their value determines their identity rather than any distinct characteristics they may possess [11]. For instance, currencies such as ETH (Ethereum) and dollars are fungible since one unit of ETH can be exchanged force another unit of a dollar, or vice versa, without any difference in their value [12]. As a result, NFTs are an excellent means of establishing ownership of digital content like music, artwork, or artifacts. By utilizing blockchain technology, NFTs establish a digital record of ownership and transfer, guaranteeing that every transaction is documented and validated through a decentralized network. This incorporation of blockchain technology ensures the authenticity and exclusivity of each NFT, preventing any possibility of replication or duplication and offering a dependable and transparent approach to demonstrate ownership of digital assets [13]. Non-fungible tokens (NFTs)have gained significant traction recently as they use blockchain technology. Such usage provides verifiable proof of ownership for the item NFT is associated with.

**Features of NFTs:** NFTs possess distinct characteristics that set them apart from other types of digital assets and grant them versatility for various purposes. NFTs possess various features as shown in below fig [5]

A diagram of a company

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**1)** **Unique:** Each NFT is unique and cannot be replaced or replicated. This allows for creation of one-of-a-kind digital assets that can be verified and tracked [5].

**2) Ownership:** NFTs use blockchain technology to record and track ownership, which allows for the token’s ownership transfer in a secure and verifiable way [5].

**3) Interoperability:** NFTs are created using blockchain technology, making it possible for them to be easily integrated with other blockchain-based platforms and applications, making them more versatile and useful [5].

**4) Decentralized:** NFTs are built on decentralized blockchain technology, which ensures that they are not controlled by any central authority, making them more secure, transparent, and resistant to censorship [5].

**5) Immutable:** All NFT transactions and ownership information are stored on an immutable blockchain ledger, which cannot be altered or deleted [5].

**6) Programmable:** NFTs can be programmed to include rules and restrictions that govern how the asset can be used or transferred, giving creators more control over their digital assets [5].

**7) Verifiability:** Minting, transferring, or burning NFTs are all transactions permanently stored on the blockchain; therefore, the full history of an NFT can be verified [5].

**8) Flexibility:** A wide variety of digital assets, such as virtual real estate, music, films, and art, may be represented by NFTs [5].

**3. Protocols, Standards and Properties of NFT:**

**(From Paper [3])**

This section presents two basic models of NFT schemes, with emphasis on their protocols, token standards and key properties.

**3.1 Protocols**

[3] The establishment of NFT requires an underlying distributed ledger for records, together with exchangeable transactions for trading in the peer-to-peer network. This report primarily treats the distributed ledger as a special type of database to store NFT data. In particular, we assume that the ledger has basic security consistency, completeness, and availability characteristics. Based on that, we identify two design patterns for the NFT paradigm. The former protocol is established from top to bottom with a very simple yet classical path: building NFTs from the initiator, and then sell them to the buyer. In contrast, the later route reverses this path: setting a NFT template, and every user can create their unique ontop NFTs. We separately provide detailed protocols of these two design patterns as below. To be noted, for both, they still follow a very similar workflow when executed on blockchain systems (cf. in below Fig), meaning that different designs will not change the underlying operating mechanism.

**Top to Bottom.** For the first design (e.g., CryptoPunks [20]), an NFT protocol consists of another two roles: NFT owner and NFT buyer.

- **NFT Digitize.** An NFT owner checks that the file, title, description are completely accurate. Then, s/he digitizes the raw data into a proper format.

A diagram of a system

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**- NFT Store.** An NFT owner stores the raw data into an external database outside the blockchain. Note that, s/he is also allowed to store the raw data inside a blockchain, despite this operation is gas-consuming.

**- NFT Sign.** The NFT owner signs a transaction, including the hash of NFT data, and then sends the transaction to a smart contract.

**- NFT Mint&Trade.** After the smart contract receives the transaction with the NFT data, the minting and trading process begins. The main mechanism behind NFTs is the logic of the Token Standards that can be found in Section 3.2.

**- NFT Confirm.** Once the transaction is confirmed, the minting process completes. By this approach, NFTs will forever link to a unique blockchain address as their persistence evidence.

**Bottom to Top.** For this design, the protocol consists of two roles: NFT creator and NFT buyer. In most cases, a buyer can also act as a creator because an NFT product is created based on random seeds when a buyer bids for it. This extends the functions in terms of user customization. Here, we use the superscript ∗ to highlight differences compared with the previous one.

**- Template Create∗.** The project founder initiates a template via the smart contract to set up several basic rules, such as different features (character style, weapons, or accessories) in the game.

**- NFT Randomize∗.** Once a buyer bids for an NFT, s/he can customize the NFT product with a set of additional features on top of basic lines. These additional features are randomly selected from a database that was predefined at the initial state.

**- NFT Mint&Trade.** The minting and trading process starts once the corresponding smart contract is triggered.

**- NFT Confirm.** All the procedures are conducted through smart contracts. The generated NFT will be persistently stored on-chain when the consensus procedure has been completed.

In a blockchain system, each block possesses a finite capacity. When this capacity is reached, subsequent transactions are queued for inclusion in a future block that links back to the original data block. Consequently, these interconnected blocks form a permanent and enduring historical record. The NFT system exemplifies a blockchain-based application. Each time an NFT is minted or sold, a new transaction is necessitated to trigger the smart contract. Once the transaction is confirmed, the NFT's metadata and ownership details are recorded in a new block, guaranteeing the immutability of the NFT's history and the preservation of ownership.

**3.2 Token Standards**

In this part, we clarify token standards related to NFTs, including ERC-20 [45], ERC-721 [35], and ERC-1155 [36] (see Algorithm 1). These standards have a great impact on the ongoing NFT schemes. We discuss them as follows.

A screenshot of a computer code

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The most prevalent token standard originates from ERC-20 [45], introducing fungible tokens that can be issued on Ethereum once specific requirements are met. This standard ensures that each token is identical to another in terms of type and value, meaning any given token is equivalent to all others. This standard has fueled the Initial Coin Offering (ICO) craze from 2015 to the present, enabling numerous public chains and blockchain-based DApps [44][34] to secure initial funding. In contrast, ERC-721 [35] establishes a non-fungible token standard, distinguishing itself from fungible tokens by being unique and distinguishable from other tokens. Each NFT includes a uint256 variable called tokenId, which, when paired with a contract address, is globally unique. The tokenId can also generate special identifications, such as images in the form of zombies or cartoon characters.

Another standard, ERC-1155 (Multi Token Standard) [36], extends the representation of both fungible and non-fungible tokens. It offers an interface capable of representing any number of tokens. Unlike previous standards, where each tokenId in a contract contains a single type of token—ERC-20 deploys each token type in separate contracts, and ERC-721 deploys groups of non-fungible tokens in a single contract with the same configurations—ERC-1155 enhances the functionality of tokenId. Each tokenId can independently represent various configurable token types, including customized information such as metadata, lock-time, date, supply, or other attributes. An illustration (see Fig.2) is provided to demonstrate their structures and the aforementioned differences.

A diagram of a diagram

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**3.3 NFTs Desired Proprieties**

NFT schemes are essentially decentralized applications [43], and thus enjoy the benefits/properties from their underlying public ledgers. We summaries the key properties as follows.

**- Verifiability.** The NFT with its token metadata and its ownership can be publicly verified.

**- Transparent Execution.** The activities of NFTs include minting, selling and purchasing are publicly accessible.

**- Availability.** The NFT system never goes down. Alternatively, all the tokens and issued NFTs are always available to sell and buy.

**- Tamper-resistance.** The NFT metadata and its trading records are persistently stored and cannot be manipulated once the transactions are deemed as confirmed.

**- Usability.** Every NFT has the most up-to-date ownership information, which is user-friendly and information-clearly.

**- Atomicity.** Trading NFTs can be completed in one atomic, consistent, isolated, and durable (ACID) transaction. The NFTs can run in the same shared execution state.

**- Tradability.** Every NFTs and its corresponding products can be arbitrarily traded and exchanged.

**Applications of NFTs:**

**(From Paper [42])**

This section discusses the various applications of NFTs and how they are reshaping the future of digital assets. A summarized version of NFT application is given in Table III.

1. **Digital Art**

Digital art encompasses creative content like music, films, paintings, and images that exist in digital form. NFTs ensure the authenticity of digital art by attaching a unique hash to each piece, allowing artists to include their signature in the tokens. This process not only helps in differentiating original works from counterfeits but also ensures that each copy belongs exclusively to the buyer. Artists can also receive royalties each time their artwork is transferred to a new owner, as exemplified by Beeple's historic sale of a digital art piece for USD 69 million at Christie’s​ [14]

1. **Fashion**

The fashion industry is utilizing NFTs to leverage unique ownership, permanence, and royalty acquisition. Luxury fashion brands are embedding digital NFTs into physical articles to prevent counterfeiting and to retain exclusivity. For instance, Jacob & Co. auctioned a digital watch for USD 100,000, and RTFKT sold a virtual jacket for over USD 125,000. While NFTs may not replace physical goods entirely, they offer lucrative opportunities for luxury fashion businesses to extend their brand digitally [6] [42].

1. **Licenses And Certifications**

NFTs can streamline the verification of critical documentation by assigning unique tokens to licenses and certifications. This reduces the administrative burden of record-keeping and minimizes fraud by making documents tamper resistant. Zastrin, an education-based company, uses NFTs for course licenses and completion certificates, showcasing how educational institutions can benefit from this technology [7][8].

1. **Collectibles**

NFTs were first popularized through digital collectibles like CryptoKitties, which are unique digital kittens with distinct characteristics. Users can breed these digital pets, with the value determined by their genetic profiles. Collectibles like these helped introduce and normalize NFTs to the general public and highlighted the potential of digital scarcity and ownership in virtual items​ [14], [15], [16], [18].

1. **Boosting Gaming Potential**

The gaming industry is harnessing the power of NFTs to provide players with true ownership of in-game items and assets. This not only enhances the gaming experience but also creates a marketplace where developers can earn royalties from the sale of NFTs. Players can buy, sell, or trade these items, potentially generating profit if the value of the item increases over time. This model benefits both players and developers, creating a more interdependent and profitable business framework. [22], [19], [21]

1. **Domain Names**

Blockchain-based domain name services like the Ethereum Name Service (ENS) and Unstoppable Domains allow users to replace lengthy, complicated addresses with user-friendly names. These services, powered by the Crypto Name Service (CNS) on the Ethereum blockchain, simplify the process of creating and managing domain names, making them more accessible and easier to use [9], [10].

1. **Virtual World**

Virtual online worlds like Decentraland are using NFTs to represent assets such as virtual land, which can be bought, sold, and developed. This creates a decentralized environment where all transactions are recorded on the blockchain, ensuring trust and authenticity. Users can create and monetize their own experiences within these virtual worlds, showcasing the potential for NFTs to facilitate new forms of digital ownership and commerce. [23], [24], [25]

1. **Sports**

The sports sector has embraced NFTs for trading card systems, allowing fans to collect and trade game highlights as NFTs. This new revenue stream benefits athletes and teams, providing a unique fan experience and a novel way to connect with supporters. The NBA's Top Shot platform and the Golden State Warriors' NFT collection are examples of how sports entities are capitalizing on the NFT trend. [26]

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**Challenges in NFTs:**

**(From Paper [5] and [42])**

Below are the challenges in NFT applications, incorporating the details provided:

1. **Usability Challenges [5]**
   * **Slow Confirmation:** NFT transactions on platforms like Ethereum are slow due to low transaction speeds, leading to delays in confirming NFT minting, selling, and exchanging. This is a significant usability issue that affects the user experience.
   * **High Gas Prices:** The fees for transactions on the Ethereum network (gas prices) are high, making NFT minting and trading costly. This is due to the computational resources required for executing smart contracts, which can be a barrier to entry for many users.
2. **Security and Privacy Issues [5]**
   * **NFT Data Inaccessibility:** The metadata associated with NFTs is often stored off-chain, with only a hash stored on the blockchain. This can lead to data loss if the storage node fails, or the file address is incorrect, potentially eroding trust in NFTs.
   * **Anonymity/Privacy:** NFTs offer pseudo-anonymity, and if the link between a user's real identity and their blockchain address is known, all associated activities are traceable. This raises privacy concerns, as current privacy-preserving solutions are complex and not widely adopted.
3. **Governance Considerations [5]**
   * **Legal Pitfalls:** NFTs face a complex legal landscape with varying regulations across jurisdictions, including issues with commodities, cross-border transactions, and KYC requirements. This complexity can hinder NFT trading, especially in countries with strict regulations.
   * **Taxable Property Issues:** NFTs are not always recognized as taxable property, which can lead to financial crimes. Governments are seeking to impose tax liabilities on NFT transactions to ensure they are treated as accountable assets.
4. **Extensibility Issues [5]**
   * **NFT Interoperability (Cross-Chain):** NFT ecosystems are typically limited to specific networks, and cross-chain communication requires trusted intermediaries, which undermines the decentralization aspect of blockchain.
   * **Updatable NFTs:** Updating NFT systems is difficult due to the need to align with blockchain protocols. This requires careful management of forks to maintain system integrity and prevent adversarial behaviors.
5. **Intellectual Property Rights** 
   * True ownership of NFTs can be difficult to establish, as replicas can be minted, and purchasing an NFT does not always grant intellectual property rights. This lack of clear regulations poses legal ambiguities and enforcement issues [27], [28].
6. **Cyber Security**
   * The NFT market is vulnerable to cybersecurity threats, including impersonation, copyright theft, and hacking. The theft of NFTs from Nifty Gateway users is a notable example of the security risks associated with NFTs [4].
7. **Smart Contracts**
   * The development and security of smart contracts are major concerns, as evidenced by the Poly Network hack. The primary language for Ethereum smart contracts, Solidity, lacks clear security standards, and developers face challenges in creating secure contracts [31].
8. **Environmental Impact**
   * The energy consumption of blockchain technologies like Ethereum and Bitcoin is high, raising environmental concerns. The electricity usage of these networks is comparable to that of small countries, and the widespread adoption of blockchain could significantly impact global temperatures [32], [33].

These challenges highlight the need for ongoing research and development to address the usability, security, privacy, governance, and environmental issues associated with NFTs.

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