Digital Transformation of Finance
Decentralization, Accessibility and Efficiency

Abstract

Organizations such as institutions and large companies have to adapt to technological advances. They do this through a digital transformation process. In this paper we concentrate on finance industry which entered the first stage of digital transformation already in the 1960s. We look at the effects of digital transformation on finance with a particular emphasis on decentralization, accessibility and efficiency of novel approaches. First we establish a circular pattern of technological development and look at finance through that framework. Then we look into the process of digital transformation itself and how finance industry progressed through the stages of transformation, i.e. digitization, digitalization and digital transformation stage. Finally, we examine more closely two case studies: (1) possibility of decentralized and efficient real time transaction networks and (2) peer-to-peer lending, which allows individuals to offer loans to each other.

Index terms— digital transformation, digitization, digitalization, transaction networks, peer-to-peer lending, blockchain

1 Introduction

Finance industry plays an important role in the modern world. Its significance can be seen in its share of the gross domestic product which in 2018 amounted to 7.4% in the US [1]. By offering financial services such as financial transactions and loans, it acts as an intermediary and makes connections between other industries as well as borrowers and savers possible [2]. To keep up with advances of digital technology and its increasing inclusion in all parts of the society and life of individuals, finance, like other industries, is undergoing digital transformation; that is, adaptation of the underlying business processes to changes in technological environment by using new technologies, changing existing business models and inventing completely novel business models [3].

In the past, the only way to access financial services was through specific institutions like banks and credit unions. This makes traditional finance centralized and dependent on institutions whose consumer confidence levels decreased severely after the Great Recession in 2008 and only started to recover after 2013 yet, as of 2021, still failed to reach levels seen prior to the Great Recession [4]. Novel technologies such as blockchain could, however, help traditional institutions regain trust of the consumers or offer alternative decentralized forms of finance. Moreover, increased connectivity of the modern world through internet, and in particular the World Wide Web, made alternative ways of offering financial services possible and thereby decreased levels of centralization within the finance industry. Examples of alternative finance are equity, reward or donation-based crowdfunding and peer-to-peer (P2P) lending.

Before introduction of computers in finance, access to financial services was limited by the existence of bank branches (with post offices serving as alternatives in some places). To deposit or withdraw money from an account, for example, one had to go to a local bank branch and interact with a bank clerk. Nevertheless, even though the number is rapidly decreasing, 2017 still saw more than 22% of adults in the world without a bank account [5]. Furthermore, individuals with unsteady income or other inadequacies considered to decrease creditworthiness are often unable to access traditional lending market. In 2010, more than 19% of adults in the US, with some age and racial groups disproportionately affected, had no access to the lending market [6]. However, similarly to the effect on centralization levels, crowdfunding and P2P lending could, through expansion of the supply side, offer improved access to financial services. Prevalence of internet in all parts of the world also indicates that the incumbent banks gain a lot from making their services available online through web or mobile banking. What is more, the fact that about two-thirds of individuals without a bank account have a mobile phone and internet access implies that digital transformation could indeed improve accessibility of financial services [5].

Although transaction times decreased significantly over the past decades, efficiency of the system still remains low. Due to increasing digitalization, depending on the distance, the last century recorded a reduction in the financial transaction times from weeks to a few days. However, because business processes in incumbents still consist of many manual steps and depend on humans, there are still increased transaction times during bank holidays or weekends. Take for instance the international electronic transfers over the SWIFT network, the largest global network between financial institutions, these take, on average, a few days because funds have to be transferred between many intermediate institutions [7]. These problems, which also negatively affect accessibility of the services, could be solved through increased automation.

1.1 Cycle of development

Technological progress in various industries seems to follow a circular pattern where *technological development* which results in creation of new products or processes affects *user behavior*. Changes in the user behavior of younger generations, particularly those that grow up with new technology then result in modification of *consumers' expectations* which again prompt further technological development. To exemplify, during the last two centuries notable advances repeatedly happened in telecommunications industry due to consumers' expectations for ever better connectivity. From telegraphs, telephone networks, development of the internet and portable phones, up to smartphones, consumers' expectations for better connections repeatedly lead to development of new devices, networks and infrastructure. These advancements changed user behavior which accordingly affected other industries as well.

Figure 1 demonstrates one instance of technological advancement in finance which resulted in development of mobile banking. Appearance of smartphone is chosen as a starting point. Its existence changed consumer behavior in such a way that consumers spent a lot of time with the device and took it everywhere with themselves. Developed habits eventually altered consumers' expectations in a way that they expected to be able to access, among other functionalities, their financial accounts and corresponding services such as bank transfers, from their smartphones. In consequence, this prompted the development of smartphone applications, which offered the desired functionality, and thus lead incumbent organizations further towards digital transformation of their offerings.

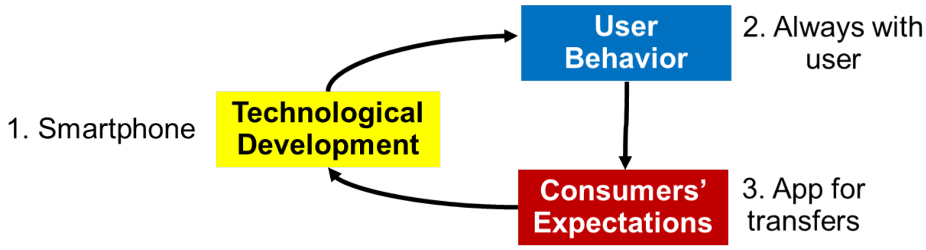


Figure 1: Circular pattern of technological development with an example in finance.

1.2 Consequences and challenges of digital transformation

Digital transformation has influence on many participants and areas of society, not least individuals, nonprofit organizations, entrepreneurship and political campaigns. With digitalization of the lending market, individuals can take part on both sides of transactions, meaning they can now act as lenders as well. The result is a broader loan supply with increased competition among lenders. This opens an alternative channel for individuals unable to access the traditional finance and promotes development of small businesses. Furthermore, through donation-based crowdfunding, digital transformation often increases the amount of funds raised in political campaigns [8]. Easier access to fundraising increases the variance of donors, lenders and investors. Consequently, behavior of backers changes as well. Type and amount of information given to backers and campaign starters affects the fundraising success. For example, giving potential supporters information about the previous campaign donors and amounts donated makes campaigns more successful [9]. Nevertheless, data from prosper.com lending platform shows that even though P2P lending does improve accessibility, visible in the fact that individuals with lower credit scores made up the majority of borrowers, only 5.5% of such borrowers successfully raised funds [10].

There are many challenges associated with digital transformation. In finance industry, high levels of security and privacy are crucial. However, increased digitalization resulted in numerous cases where customer data was stolen from banks or small startup firms that aimed to disrupt the finance industry. Such cases are unfortunately still occurring. For example, in 2020 an Indian startup Chqbook suffered a data breach which exposed 2 million credit score records, and in 2019 an attack on Capital One Financial Corp. bank exposed identity of 100 million customers [11]. Additionally, some of the novel technologies like cryptocurrencies are associated with decreased regulation and a large number of scams.

Abundance of data allows many transformations to use artificial intelligence (AI) and machine learning (ML) to automate decision processes like investment opportunities and loan approval. However, automated credit scoring has to take into account mutually exclusive definitions of fairness and potential biases in the used model and the data [12]. Moreover, since these systems often use black-box models, whose decision process is not understandable for humans, regulators started requiring from businesses to offer their customers explanations of decisions that were made by such models [13]. Crowd-wisdom approaches like P2P lending are also not immune to this issue. For example, existence of a photo in borrower's listing, or merely their mood in the photo, can affect interest rate of the loan [10].

The rest of the paper is structured as follows: first we look at stages of digital transformation through which finance industry went and is going through at the moment.

Thereafter we concentrate on two case studies. We look into the specifics of (1) real time transaction networks that are global in scope and (2) P2P lending. In conclusion we discuss and summarize the paper.

2 Stages of Transformation

2.1 Digitization

Digitization refers to the introduction of digital computers into industry [3]. One of the first hallmarks of digital transformation in financial industry was the introduction of automated teller machines (ATM) which allowed individuals to access their financial accounts through a machine. Authentication and authorization was done through plastic ATM cards and the corresponding PIN code. Users could check an account balance, make deposits and withdrawals from their accounts and initiate transactions. Furthermore, ATMs allowed bank customers to make transactions without going to a bank branch and interacting with bank clerks. Another advantage made possible through digitization is electronic fund transfers (EFT) between bank accounts which sped up transactions significantly and represent a stepping stone for further digitalization of the finance industry. Today, all types of transactions, including wire transfers, direct debit and deposit transactions, are electronic.

2.2 Digitalization

Digitalization is the second stage of digital transformation in which the use of computing devices and networks becomes so significant that it makes changes to existing business models within an industry [3]. Examples of digitalization in financial industry are online and mobile banking, as well as online trading. Following the transformation circle from the previous section, we can see that the internet — and in particular the web as an application on top of it — were a technological development which changed the behavior of users who then wanted to be able to access their financial services over the web. In online banking many of the services that previously had to be completed with the assistance of bank clerks or ATMs were included as features within a web application and this way met customers' expectations. Mobile banking was another step which satisfied customers' expectations that arose from the appearance of smartphones. While in mobile banking the same functionalities as in online banking are implemented in a smartphone application, online trading platforms provide a different service. They provide software for following the markets and allow individuals to trade financial assets like currencies or stocks.

These adaptations resulted in significant changes of business processes in retail banking. The effect is primarily seen in reduced need for branch offices and ATMs. Since technological advance allowed the online use of services without interaction, this prompted the development of purely online banks. Online banks have a reduced need for personnel since most of the functions could be done through web or mobile applications. As a consequence of the COVID-19 pandemic, progress of digitalization speeds up in all parts of the world and the movement of services online can be seen on the consumer side, with ATM usage falling by 47% and 46% in April 2020 in India and UK respectively, as well as business side, with more than 2,150 ATMs and 175 bank branches closing in Australia [14].

Increase in the efficiency of digital transactions could also be perceived as an improvement of the existing business models. Although many of the modern approaches to reduce transfer times are based on blockchain technology, there are also schemes such as SEPA Instant Credit Transfer (SCT Inst), which are agnostic of the underlying technology and do not define how funds are exchanged, as well as, efficient payment networks like VisaNet that are based on centralized infrastructure.

2.3 Digital Transformation

In digital transformation as the last stage, changes to the fundamentals of the industry create completely novel business models [3]. While in previous stages existing business processes were made more efficient and accessible, in this stage changes of business models themselves enable improvement in other aspects such as decentralization. Various technological advancements in this stage are known under the term *FinTech*. With many hallmarks of digital transformation mentioned below, alongside academic research, there are also often smaller FinTech firms and open-source initiatives that are concentrated on their further development or commercialization.

In order to ascertain the impact of technological development on the finance industry, J. W. Schindler looks at the *depth* of innovation which depends on the effect an innovation has on the fundamentals of the industry [15]. In general, innovations that introduce new business models could mostly be classified into platforms that facilitate the wisdom of the crowd and applications built using a blockchain technology. Both of these classes could be further improved and automated through an application of AI including ML. Depth of innovation of the approaches that use the wisdom of the crowd is mainly in the fact that individuals and smaller companies that could otherwise not overcome the regulatory hurdles are allowed to participate on the lender or investor side. Even though this increases the competition on the supply side, due to decreased regulation, investors are also increasingly at risk of fraud [16].

Another innovative concept that is currently being researched are central bank digital currencies (CBDC). They could in principle be implemented with a (distributed) database controlled by a central bank. Such implementation represents a centralized scheme with a single point of failure but high efficiency and scalability levels. CBDCs could potentially allow transactions without any third parties except the central bank. Recently, several CBDC projects were completed in Ecuador, Ukraine and Urugay, and currently, Canada, China and Sweden are testing hybrid models with banks as intermediaries that handle payment services [17].

Blockchain-based applications are more fundamental than the approaches facilitating the wisdom of the crowd. Digital currencies built on blockchain are called cryptocurrencies and the underlying networks are usually open to everyone, decentralized and global in scope. Blockchain is also considered to be a technology that could be used to support CBDC. Nevertheless, central bank of China claims that an infrastructure behind CBDC would have to handle 300,000 transactions per second (TPS) to service the retail market in China and currently available blockchain platforms are not able to support such volume of transactions [17].

Another presently evolving area is decentralized finance (DeFi) which uses the possibility of running small programs on Ethereum blockchain platform to automatize, decentralize and make more transparent the provision of financial services [18]. Some examples of such services are decentralized exchanges, decentralized (peer-to-peer) lending platforms and stablecoins whose value is associated with fiat currencies.

3 Case Studies

3.1 (Global) Real Time Transaction Networks

Nowadays, cash is becoming increasingly obsolete, with more than two-thirds of all consumer payments being electronic [19]. There already exist centralized networks that allow customers to make transactions in real time. We first briefly look at one such traditional, centralized network and its infrastructure and then at the possibilities for decentralized networks with comparable transaction times.

At present, SWIFT is the most commonly used scheme for updating of bank accounts and money exchange between banks [7]. The problem with SWIFT, however, is that it is slow because every transaction is verified as it passes through many financial institutions on the way from the sending to the receiving institution within the SWIFT network. For this reason, proprietary networks have been developed to process payments between merchants and consumers that offer much better performance. One such example is VisaNet, the largest payment processing network in the world.

VisaNet is the network which processes transactions of the visa-branded debit and credit cards [19]. It is a proprietary global transaction processing network that makes real time transactions possible. Visa has data centers all around the world which are connected with about two million kilometers of fiber optic cables. The infrastructure behind VisaNet is built using System Z mainframe computers running z/Transaction Processing Facility (TPF) operating system that is optimized for rapid processing of transactions with high reliability and availability [20]. VisaNet can handle more than 65,000 transactions per second with high availability visible from the fact that for the last 20 years there have been no failures recorded during days with peak transaction volume [21], [22].

3.1.1 Blockchain-based payment networks

Blockchain was first used as an underlying data structure for the **Bitcoin** cryptocurrency [23]. It facilitates creation of decentralized payment networks without the need for third-parties. Blockchain technology usually refers to either a *blockchain data structure* or the supporting P2P network called *blockchain network*. Blockchain platforms such as Bitcoin or Ethereum consist of both of these elements. Combined together, data structure and the network allow network participants to agree on a single global state. This makes it possible to have a distributed and immutable global storage, which in most cases relies on the assumption that the majority of the network's computing power is not controlled by malicious actors. In order to achieve its properties, blockchain makes extensive use of asymmetric cryptography schemes such as digital signatures, hash functions and data structures such as Merkle trees.

In Bitcoin, blockchain serves as a distributed ledger. Every user who wishes to participate in a Bitcoin network has to create at least one account which consists of a unique pair of public and private keys [23]. Data in a blockchain is stored in form of ordered transactions. In general, every transaction changes the global state on which the blockchain network participants agree. Specifically, in case where blockhain network serves as a payment network for a cryptocurrency such as Bitcoin, transactions represent payments,

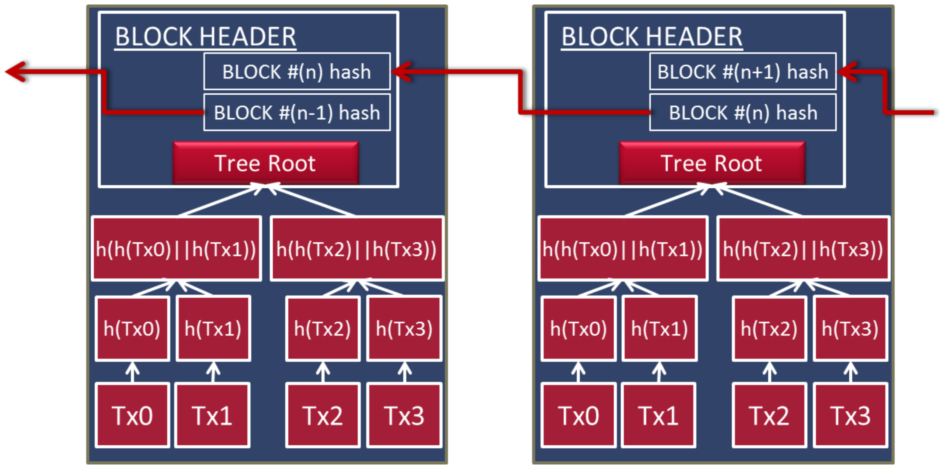


Figure 2: Blockchain data structure [23]: h is a collision resistant hash function, $||$ represents concatenation and arrows represent dependencies.

i.e. the exchange of coins between a transaction sender and receiver. In order to associate every transaction with a sender account and make transactions indisputable, every transaction includes a digital signature signed with a private key of the sender. Since other network participants have access to the public key of the sender, they can verify the authenticity of the transaction. Transactions in a simple blockchain where a single coin is transferred through a transaction look as follows [23]:

$$(input\ transaction, receiver, signature) \tag{1}$$

where *input transaction* refers to the hash of the transaction through which the sender received coins, *receiver* is the public key of the receiving account and *signature* is signed with the private key of the sender that was the receiver in the input transaction.

The global state is represented through transaction history [23]. Account balances can, thus, be computed through aggregation of coins associated with transactions that were not used as input transaction [24]. For instance, Alice's balance can be computed by summing up all transactions that were not used as input transactions but included her account's public key in the receiver field. Now, in order to prevent a situation in which Alice spends the same amount of coins twice, network participants have to share the same history of transactions. This is implemented by packaging transactions into blocks.

Inclusion of transactions into blocks that are created in regular intervals (epochs) gives rise to a 'chain of blocks' (see Figure 2). Every block consists of a block header which contains its own hash, a hash of the previous block and a root of a Merkle tree [23]. Since blocks are linked to each other with hashes, any change in one of the blocks alters its hash and thereby breaks the chain. The field containing the previous block's hash in the block following the altered block becomes invalid.

Transactions in a block are stored in leaves of a Merkle tree (see Figure 2) which is built by at first hashing transactions and then repeatedly hashing the concatenation of the child nodes to create a parent inner node [25]. This process is repeated up to a root node. The structure of a Merkle tree makes it easy to verify the inclusion of individual transactions in a block even if one only has access to the tree root and sibling nodes on the path to the tree root. For example, if one wants to verify the inclusion of the transaction `Tx1` in `BLOCK #n` in Figure 2, apart from the tree root, only $h(\texttt{Tx1})$ and $h(h(\texttt{Tx2})||h(\texttt{Tx3}))$ nodes are needed. For this reason, network participants can decide to locally store only block headers on their machines and still be able to verify transactions. A major advantage of such lightweight approach is a significant decrease in storage requirements for participation because keeping a local copy of the full Bitcoin blockchain that includes transactions (as of October 2021) requires more than 360 GB of space [26].

Now we turn to the blockchain network and the way network participants agree on inclusion of new blocks in the blockchain. At the start of the block creation epoch, a network participant can collect transactions that are not yet included in any of the blocks and include them into a new block [24]. This process is called *mining* because in order to attach new blocks users have to solve a cryptographical puzzle and are potentially rewarded for their work. Since the local state of the network participants has to agree with the global state, there is need for a mechanism that allows network nodes to reach a consensus on the global state.

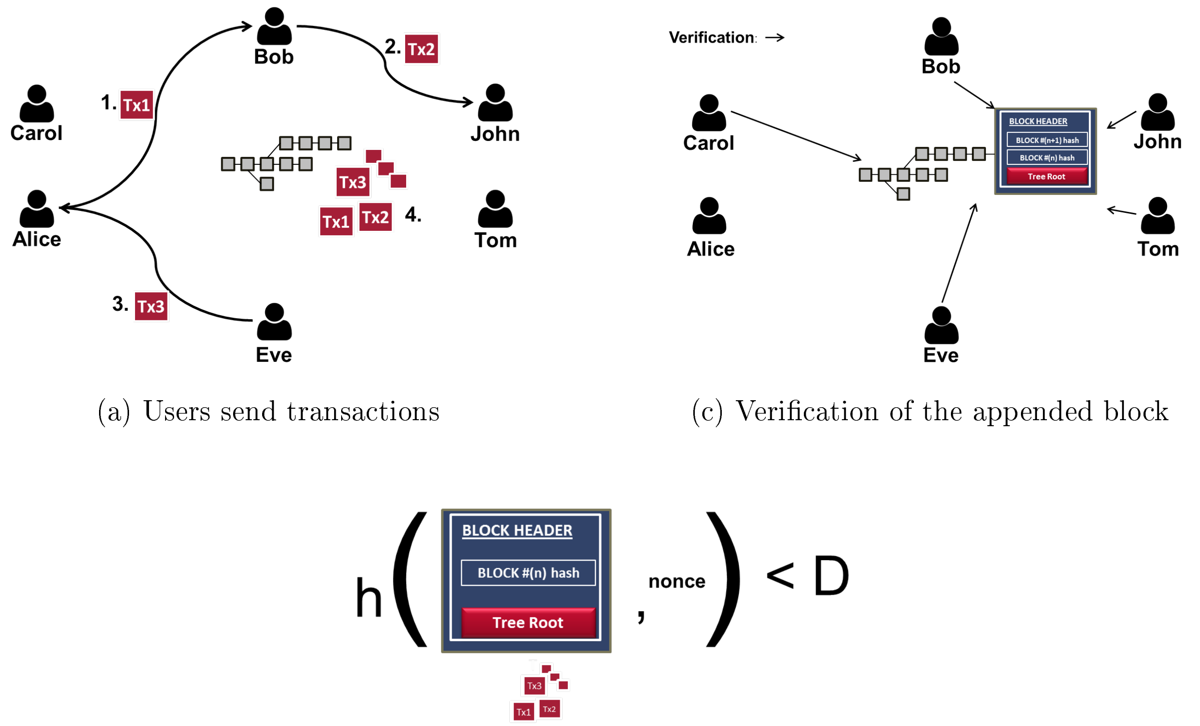
Consensus mechanism is used to prevent double-spending which happens when an attacker (i.) makes a payment with transaction `TxPay` which gets included in the next block and then (ii.) successfully creates a fork of the blockchain where it replaces a block that contains `TxPay`. Since the longest branch is considered to be the main branch, in order to make the rest of the network accept her fork as the main branch, attacker has to extend their fork faster than the main network extends the main branch [23]. Bitcoin uses the *Proof-of-Work (PoW)* consensus mechanism whose main disadvantage is that it needs a lot of computational resources [24]. Currently, the energy footprint of Bitcoin mining is larger than the energy footprint of the Philippines [27]. Despite that, the main disadvantage of blockchain networks for use in transaction payment processing is the problem with scalability which result in throughput of only 3-5 TPS in Bitcoin network [21].

The inclusion of new blocks and the process of Bitcoin mining is shown in Figure 3 and can be illustrated as follows:

(a) 1. Alice sends transaction `Tx1` to Bob (Figure 3a).
    2. Bob sends coins through transaction `Tx2` to John.
    3. Eve sends transaction `Tx3` to Alice
    4. Further transactions

(b) Network participants that try to append new blocks are called *miners*. They collect unassigned transactions which they receive over the network. In order to create a block, miners have to find a nonce, i.e. a number smaller than 2^{32}, which hashed together with the newly created block gives a number lower than the difficulty D. Since there might be no solution for a certain block, content of the block might have to be modified a bit (e.g. timestamp could be changed) and tried again. This process where the network participants repeatedly hash the created block with the nonce is called *mining* (Figure 3b).

(c) User who first published a block with the correctly solved hash puzzle is rewarded a certain number of coins and their block is appended to the global state. Other network participants verify the validity of the new block by checking whether the hash of the new block is lower than the difficulty level D and checking whether



(a) Users send transactions

(c) Verification of the appended block

(b) Hash puzzle. h is a hash function.

Figure 3: Blockchain network

the hash of the previous block is included in the header of the newly mined block (Figure 3c).

3.1.2 XRP Ledger

Although most of the payment networks associated with cryptocurrencies are public and anyone can become a network participant, in *permissioned* blockchain networks access to the network is restricted [24]. For this reason, permissioned blockchains require a single or multiple central authorities that are in control of the blockchain. While this makes permissioned blockchains less decentralized and increasingly trust-based, it also makes them more efficient by making them scalable and less computationally intensive because they can use simpler consensus mechanisms.

XRP Ledger is a global permissioned blockchain network which is at the moment able to process 1,500 transactions per second and claims to be able to match VisaNet's performance [21]. In XRP Ledger network there are two kinds of network participants: (1) validators who take part in the extension of the XRP Ledger blockchain and (2) tracking servers that just distribute client's transactions [28]. XRP Ledger uses an XRP ledger consensus mechanism that is not computationally expensive and consists of trusted validators agreeing on a set of transactions which they wish to include in the ledger. Consensus is round based and starts with each validator proposing a set of valid transactions to include in the next block. In every round validators (1) add to their set of valid transactions other transactions that are endorsed by a percentage of validators higher than threshold T and (2) remove from their set of valid transactions other transactions that are not endorsed by a majority of other validators [28]. In every subsequent round threshold T is increased and when more than 80% of the validators agree on a set of transactions, it gets included in XRP Ledger. Unlike miners in Bitcoin, validators are not rewarded for their work in XRP Ledger. Finally, since there are only 36 validators in XRP Ledger, it is arguable whether XRP Ledger can be considered to be a decentralized network [21].

3.1.3 Ethereum 2.0

Ethereum is a globally distributed computational platform built on blockchain that supports *ether* cryptocurrency. Distinctive feature of Ethereum is the implementation of smart contracts, i.e. small computational programs that can run on Ethereum blockchain. When a smart contract is deployed on Ethereum, it is associated with a contract account that is distinct from user accounts and is controlled by the code in the smart contract. Such use of smart contracts allows higher levels of automation and forms the basis for DeFi [18].

Nevertheless, Ethereum network currently suffers from the same scalability and sustainability issues as Bitcoin network. With transaction throughput of 15 TPS and high energy footprint caused by the use of PoW consensus mechanism [21], Ethereum at the moment does not present a viable alternative to centralized transaction networks like VisaNet. However, an update of the Ethereum platform to Ethereum 2.0 is in progress. This update is supposed to bring significant improvement to scalability and sustainability of Ethereum when it is finished. Team behind Ethereum 2.0 claims that the network will be able to support 100,000 TPS [29]. Below we look at two main innovations that enable the efficiency improvements of Ethereum 2.0: PoS and Sharding.

To solve sustainability issues, Ethereum plans to transition from PoW to *Proof-of-Stake (PoS)* consensus mechanism. Agreement on the next block in PoS does not involve solving computationally difficult tasks. Instead, network participants that wish to earn ether by creating or validating new blocks have to stake more than 32 ether by sending it to an account associated with a deposit smart contract [30]. These participants are called *validators* because at regular intervals, one of the validators is chosen to create the next block with a probability to choose Bob being proportional to the share of Bob's deposit among the deposits of all validators. Validators that were not chosen to create a new block have to validate the created block by signing an 'attestation' in which they define which block they consider to be the latest in the chain. Validators that fail to make or make conflicting attestation are punished by reducing their deposit. The reward or a penalty a validator gets depends on actions like the production of attestation, correctness of properties in the attestation and the number of other validators that did the same actions [30]. For every action the reward R awarded to validator i is calculated as follows:

$$R = (-1)^P \cdot S \cdot k \cdot \frac{D_i}{\sqrt{\sum_{j=1}^{n} D_j}} \tag{2}$$

where $P \in \{0, 1\}$ represents a penalty and describes whether the validator's action was inappropriate, S is the share of validators that behaved correctly, k is a constant and $D_1, \ldots, D_n$ represent validators stakes with D_i representing the stake of validator i. First steps towards the introduction of PoS have already been made with the introduction of 'the Beacon Chain', a blockchain that is at the moment still independent of the main Ethereum chain [31].

In order to make Ethereum scale without requiring a lot of computational resources from the network participants, Ethereum plans to introduce *sharding*. Through sharding, the main Ethereum chain will get replaced by the beacon chain and 64 shard chains [30].

The beacon chain is responsible for the coordination while transactions are stored on shard chains. After sharding is introduced, at the start of every epoch PoS validators will be randomly assigned to shard chains where they will sign attestations according to the PoS mechanism [30], [32]. Further, when a new block is appended to a shard chain A, two-thirds of attestations that were signed by the validators assigned to chain A along with the header of the new block will be included into a block on the beacon chain. This way through the assignment of validators to different chains and parallelization of the validation parallel processing of transactions can be achieved. Sharding is currently (October 2021) expected to be introduced in 2022 [31].

3.2 Peer-to-peer (P2P) Lending

Peer-to-peer lending online platforms are two-sided markets that offer any entities such as individuals or organizations the possibility to act in roles of both borrowers and lenders. Through use of the wisdom of the crowd P2P lending could potentially improve welfare of both sides in the lending market. However, the sector has dissimilar outlooks in different parts of the world. While the market share of P2P lending platforms is the highest in China [16], in 2013 the sector was still nascent in the US and UK with less than 2% of the market share [33]. However, owing to recent platform failures, P2P lending recorded negative growth rates in China. By contrast, in the US and UK it was characterized by high growth rate.

P2P lending, on the one hand, increases accessibility and decentralization of the lending market for individuals by providing a way for them to issue loans. On the other hand, accessibility depends on credibility and stability of the online platforms, which, however, sometimes prove to be scams as was the case with one of the largest P2P platforms in China, where more than \$8 billion was stolen from the lenders [16]. Furthermore, although data from LendingCrowd platform shows that broader loan supply offered by these platforms results in improved interest rates for borrowers on all creditworthiness levels, there are also conflicting results found in German P2P lending platform where no improvement in interest rates compared to banks could be observed [34]. Finally, through use of ML and historical loan data provided by some of the platforms, decisions about whether to offer a loan or not can be automated. This results in increased efficiency, but surprisingly also in improved fairness because in traditional P2P lending decisions of the crowd are often influenced by sensitive attributes of the borrowers such as their age and gender [35].

Fu, Huang and Singh show that ML models can outperform the wisdom of the crowd in approximation of borrower default probabilities [35]. What is more, automation of the loan allocation process using default probabilities determined by the model could improve overall welfare in P2P lending. On the one hand, this is achieved though increase in loan accessibility for the borrowers, as can be seen in the fact that borrowers funded by the ML model in [35] have lower average credit scores than those funded by the crowd. On the other hand, profitability of the loans made according to the ML model was also higher. In the following, we look at the way ML models work in P2P lending.

As can be seen in Figure 4, lenders in P2P lending can see information about the borrowers presented in form of a number of attributes such as income or expenses that can be represented numerically or categorically. Such historical borrower data that is labeled with borrower's default information can be used for training, i.e. finding optimal parameters of an ML model. Assuming that there are n borrowers, each represented with

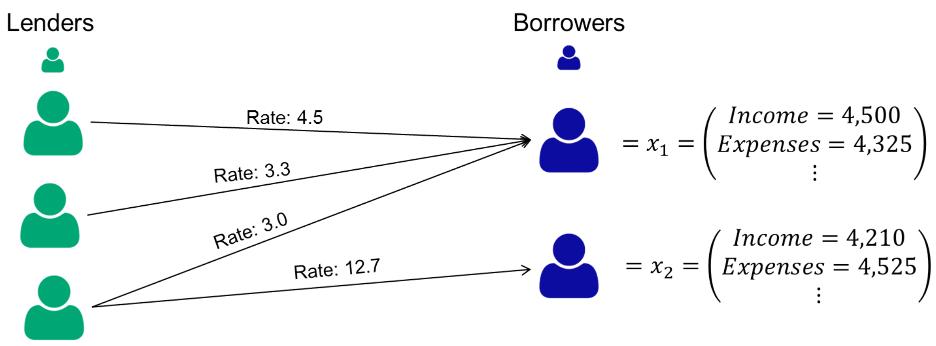


Figure 4: Wisdom of the crowd in peer-to-peer lending.

d attributes, information about them can be collected in a matrix $\boldsymbol{X}$, with row vectors $\boldsymbol{x_1}, \boldsymbol{x_2}, \ldots, \boldsymbol{x_n} \in \mathbb{R}^d$ representing borrowers and binary values $y_i \in \{0, 1\}$ for all $i \in \mathbb{N}$ s.t. $i \leq n$ can be used to represent borrower's default status. Further, categorical attributes like profession can be represented with a one-hot-encoding. Data organized like in (3) can be used to train an ML model.

$$(\boldsymbol{X}, \boldsymbol{y}) = \left(\begin{bmatrix} \boldsymbol{x_1} \\ \boldsymbol{x_2} \\ \vdots \\ \boldsymbol{x_n} \end{bmatrix}, \begin{bmatrix} y_1 \\ y_2 \\ \vdots \\ y_n \end{bmatrix} \right) \tag{3}$$

Figure 5 illustrates the process for training a model that can be used to predict a probability of default given borrowers attributes. Nevertheless, sensitive attributes, like race and gender, and other attributes correlated with the sensitive attributes, like location and profession have to be carefully handled to avoid bias and ensure fairness. This could, in an extreme case, include removal of all sensitive attributes and attributes correlated with them from the data set. The approach suggested in [35] is to make all attributes independent of the sensitive attributes before training the model. Surprisingly, they find that after debiasing their model still performs better than the crowd, whose decisions are still biased as well. The limitation of the results is, however, that they are based on one notion of fairness and the same might not apply to other notions of fairness [12].

After debiasing, the model is trained on data by minimizing the 'loss' function l which describes the distance between the model output and the label corresponding to the input:

$$\theta^* = \arg\min_{\theta} \sum_{i=1}^{n} l(y_i - f_\theta(\boldsymbol{x_i})) \tag{4}$$

where θ^* represents trained model parameters and f_θ represents a prediction function. An alternative to the up front debiasing of the data is adding a term that considers fairness to the loss function intended to force the model to learn optimal parameters while considering the fairness aspect. Eventually, after the loss function is minimized on the training data, prediction function of the trained model (5) can be used to predict the probability of borrower default and thereby help investors make correct decisions.

$$\begin{aligned} f_{\theta^*} &: \mathbb{R}^d \to [0, 1] \\ \boldsymbol{x} &\mapsto y \end{aligned} \tag{5}$$

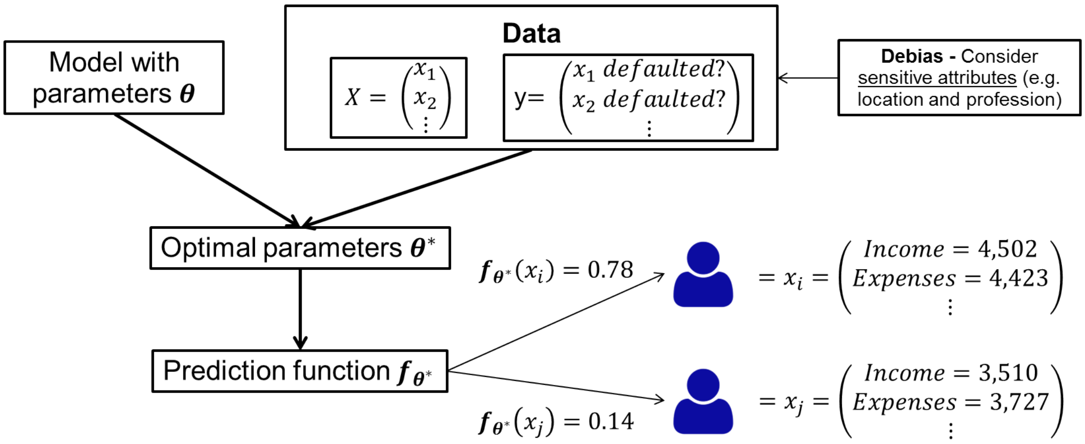


Figure 5: Application of machine learning in peer-to-peer lending.

Periodical retraining of the model with new data could also be needed because the relationship between default probability and borrower attributes could change over time.

With respect to the used model type, various ML models such as decision trees, random forests, k-nearest neighbors or support vector machines could be employed. For example, authors in [35] used XGBoost which combines decision tree model with an ensemble learning technique called boosting. Finally, because of the sensitivity of lending decisions and corresponding regulations, in case black-box models like deep neural networks are used, they should be accompanied by explainability systems that can provide explanations of model decisions [13].

4 Conclusion

On the one hand, pervasiveness of computing devices around the world suggests that accessibility of financial services will be significantly improved with digital transformation. Increased accessibility and interconnectedness enable improvements in fundraising through wisdom of the crowd. Moreover, cautious use of machine learning models, with data that is increasingly available, could potentially help reduce bias and improve overall welfare for lenders and borrowers.

On the other hand, digital transformation of finance seems to be characterized by a trade-off between decentralization and efficiency which is encountered in both (1) general infrastructure, with a difference between central bank digital currencies (CBDC) and blockchain-based cryptocurrencies, and (2) blockchain payment networks, with varying levels of access restrictions between public and permissioned blockchains. Research in mediation of the trade-off between decentralization and efficiency is ongoing with Proof-of-Stake consensus mechanism and sharding representing potential mediation strategies.

The paper first looked at a circular pattern of technological development and its manifestation in finance. Three stages of digital transformation and their examples in finance were then explored and finally, two case studies — (global) real time transaction networks and peer-to-peer lending — were presented.

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