Payment Systems in the United States and architectures enabled by Digital Currencies

by

Akshay Bagai

B.E. Mechanical Engineering,
Maharshi Dayanand University, 2005

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at the

Massachusetts Institute of Technology

June 2017

Signature redacted

Signature of Author ______________________________

Akshay Bagai
System Design and Management Program
May 12, 2017

Signature redacted

Certified by______________________________

Christian Catalini
Fred Kayne (1960) Career Development Professor of Entrepreneurship
Assistant Professor of Technological Innovation, Entrepreneurship, and Strategic Management
Thesis Supervisor

Signature redacted

Accepted by ______________________________

Joan Rubin
Executive Director, System Design & Management Program

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Abstract

A payment is a transfer of value from one party to another and cash is the simplest form of payment. However, the cost of cash transactions increases as the volume of transactions or distance between the parties involved increases. Various electronic payment systems have evolved over time to enable different types of transactions in the economy. Payment systems are now the backbone of the economy and trillions of dollars are exchanged on the payment system rails every year.

Central banks, payment processors, payment gateways, credit card issuers and banks are just a few of the counterparties which enable payments across a multitude of counterparties for their specific needs. An extremely complex technological architecture enables these transactions. Central banks are now considering the issuance of digital currencies to increase efficiency in payments.

Blockchain could potentially simplify payments systems and reduce market inefficiencies. It can provide a way for multiple counterparties to connect on the same platform and reduce the time for clearing and settlement. In this thesis, I study the technology and stakeholder needs to propose novel architectures that could be adopted for payments processing.

Acknowledgements

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Introduction

The term "payment system" refers to instruments, intermediaries, and interbank funds transfer systems which facilitate the flow of money in a country or currency area. Payment systems are now the backbone of the economy and trillions of dollars are exchanged on the payment rails every year. An extremely complex technological architecture enables these transactions.

Payment systems have moved from the backroom to the boardroom of financial institutions because of the critical role that a well-functioning payment system plays in supporting the economy. The creation of networks and systems for retail payments can also have a substantial role in supporting financial access in developing countries. A robust infrastructure to securely and reliably process modern payment instruments is necessary to successfully enhance a country's population access to modern payment instruments.[1]

Although there have been many advancements in technology, the payment systems in the United States are highly fragmented and outdated. U.S. payment offerings are far behind many countries, including Brazil, China, Korea, Switzerland and India. These countries have recently launched sophisticated real time gross settlement (RTGS) systems which allow instantaneous settlement.

In this thesis, I first introduce the concept of payments and explain the steps that must be completed in a payment transaction. In Chapter 2, I discuss the stakeholders who are involved in enabling payments and describe the payment systems that available in the US. Cash, checks, credit cards, ACH and wire transfers are the main payment systems. I also briefly compare the U.S payment systems to the rest of the world. In Chapter 3, I present the key elements of a payment system and discuss the evaluation criteria of the payment systems and the risks involved in payments. I also explore the future of payments from the perspective of digitalization of the economy. This is useful for understanding the direction of development of future systems to enable transactions.

In Chapter 4, I introduce a technology, Blockchain, which offers a paradigm change. The rationale for using a distributed ledger by the Federal Reserve Bank and the commercial banks is explored. Based on this rationale and the future demands from the payment systems, Chapter 5 proposes potential architectures that could be adopted by either Federal Reserve Bank or commercial banks to enhance the payment infrastructure.

The information in this thesis is from three types of sources: literature review, interviews with industry experts and my own analysis.

1 Background and overview of payments

1.1 Evolution of payment systems

For many centuries, people bartered and used goods or services to exchange benefits. Sea shells, rice, grain, cattle, whiskey, and tobacco were all legal tender for some time. Tobacco was legal tender in Virginia for 200 years in early America, and it was not uncommon for each state to have its currency. But as the transactions became complicated and the social structure matured, there was a need for a store of value and a common denomination for exchange. A farmer might harvest a crop only once a year, but needed other goods or services throughout the year. A store of value that would not decay with time would enable the holder to carry the benefits of produce to the future.

Durability, ease of transportation and ease of storage made metals an early choice for currency. Across western civilizations, copper, gold, and silver were commonly used as currency. With the acceptance of metal as an exchange, the economy had one of its first "standards." Although the origin is lost in time, the development of the standards made trade vastly more practical. The next major revolution was the turning of metal into coins of predetermined weight and, therefore, predetermined value.

The development of coinage was the precursor of the paper money and electronic money that followed. The state minted coins and guaranteed the exact weight and value of the coins. Coins of varying weights and worth became the "units of account" for conducting exchanges. This system made it easier to quote a price and judge the cost of goods for sale. With coins, the economy had a means of exchange, a unit of account and a store of value: the three essential characteristics of money.

Another crucial development occurred in Massachusetts in 1690. The Massachusetts government had to figure out a way to pay for an unsuccessful attempt to capture the French fortress in Quebec City. The colony issued pieces of paper that promised redemption in gold or silver—later. These pieces of paper circulated side by side with gold and silver and were treated as if they were worth the gold or silver they promised. Paper money also provided a good unit of account, although the ultimate unit was still gold or silver.

Paper money was a paramount innovation. It not only made the exchange convenient but also cheaper. This was because it was much lighter and easier to transport than gold or silver coins. It is no longer possible to redeem paper money for gold or silver or anything else of intrinsic value. The value of bills and coins comes entirely from the fact that they are a widely accepted means of tender. Therefore, bills and coins are solely aspects of an accounting system that everyone in the economy has agreed to use.

Banks evolved to safeguard the coins and precious metals and, therefore, provided a safe place to store the currency. Over the centuries, money has slowly been transformed into a number on a bank's balance sheet. Banks now maintain massive databases which store the transactions and balances of everyone who has a bank account. In the United States of America, "dollar" is the unit of account. As long as the number of dollars that each of us has is tracked and accounted for, no one has to touch a dollar bill or any other piece of paper money.[2]

Most of the U.S. population now holds funds in the banking system with the banks connected by electronic networks. It is possible to imagine the financial system as a network in which depository institutions, such as banks and credit unions, maintain an accounting ledger for its customers and businesses. The primary need to transfer value between consumers is achieved by various types of payment systems.

Electronic payment systems connect different intermediaries and enable different types of transactions in the economy. Central banks, payment processors, payment gateways, credit card issuers and banks are just a few of the counterparties which enable payments across many counterparties for their specific needs. Payment systems are now the backbone of the economy, and trillions of dollars are exchanged on the payment rails every year. An incredibly complex technological architecture enables these transactions. The term "payment system" refers to the complete set of instruments, intermediaries, rules, procedures, processes and fund transfer systems which facilitate the circulation of money in a country or currency area[3].

A well-designed payment infrastructure enables the proper functioning of markets and helps to eliminate frictions in trade. If the cost of a transaction exceeds the benefits expected from the trade, the goods might not even be exchanged. Secure and reliable payment mechanisms for the transfer of funds is, therefore, essential for economic interactions (i.e. “no payment, no trade”).

Payment systems are so important for the society that World Bank Group President, Dr. Jim Yong Kim announced a goal to provide worldwide financial access by 2020.

> ***The Universal Financial Access 2020 (UFA 2020) Goal:***
>
> ***Global:*** *By 2020, adults globally have access to an account or electronic instrument to store money and to send and receive payments as the basic building block to manage their financial lives.*
>
> *Financial access is a stepping stone for broader financial inclusion which entails a wider more tailored range of financial services being used, that are provided in a responsible manner.[4]*

1.2 Steps involved in a payment transaction

All transactions have two components. First, there is an exchange of goods or services where one party commits to either deliver a service or a good to another. The second component is the transfer of funds, in which the payer agrees to transfer the funds to payee. A payee is the final recipient of the funds. A payment is, therefore, a transfer of funds which discharges an obligation on the part of a payer towards a payee. If the payer has funds in cash, then he can settle the transaction with the payee directly. However, if the payer’s funds are in a bank, then he needs a bank to facilitate the transaction.

1.2.1 Cash transaction

The transactions are very simple, if the payer has the funds in cash. In a cash based transaction, payer and payee exchange the goods for cash and the transaction is completed. No intermediary is required to facilitate the transaction and the payments are immediate and final. Cash transactions are also censorship resistant, meaning the payer can spend anywhere without fear of being tracked.

However, there is a cost involved in accepting cash payment since it is necessary to store and protect cash from theft. The cost of cash transactions increases as the volume of transactions or distance between the parties involved increases. For example, consider the effort and cost of distributing cash salaries to all employees by a company that has thousands of employees. The economy could never have grown to trillions of dollars a year, if cash was the only mode of payment.

1.2.2 Non - cash transaction

If the funds of a payer are in a bank, then the transaction between the payer and payee has to be facilitated by the bank. The payer bank has to deliver funds to the payee bank, which can then credit the funds to the payee. One can imagine the complexities rapidly increasing because of the number of banks and jurisdictions involved. The complexities today are resolved mostly by hub and spoke models, in which a central entity facilitates payments between the banks. A non-cash transaction facilitated by an intermediary is performed in three steps:

- **Selection of payment Instruments:** A non-cash payment instrument is a tool by which payer authorizes the bank for funds to be transferred or by which a payee instructs the bank to collect funds from a payer. Payer and payee may have accounts at the same bank or different banks. Payees now have many options to transfer funds, including banking websites, mobile apps, credit cards etc.

- **Processing**: A payment network connects financial institutions with their customers as well as other participants in a payment system and in the processing of payment transactions. The transaction information is exchanged between the various parties involved in the payment chain[3].

Since most of the current payment systems are not real time, the systems perform a Netting step. Instead of settling each transaction on a gross basis, the system achieves the same result by consolidating the positions and settling one position per party.

- **Settlement:** Settlement happens when funds are transferred from the payer's bank to the payee's bank. The rules of each individual payment system define the precise moment at which finality occurs.

  Finality may occur at the moment that payment instructions are entered into the system and technically validated, the moment the payment instruction is processed and the resulting balance is settled or at any point between those two extremes.[3]

1.3 Types of payments

Today's economy today is connected and everyone has specific payment needs based on many different parameters. For example, a company that needs to disburse salary to its employees has different needs from a merchant who needs to collect the payment from a buyer. One way of categorizing payments is on the basis of the number of payers and payees involved in a particular transaction:

- **One-to-One transaction**: A payer transfers funds to the recipient. Most customer-to-customer, customer-to-business, and business-to-business payments are transactions of this type.

- **One-to-many transactions**: A payer transfers funds to multiple recipients with a single submission. These are typically transfers from businesses or governments to private households, such as salary and social security payments. One-to-many transactions are usually cleared and settled in batches.

- **Many-to-one transactions**: several payers transfer funds to a single recipient, usually on the initiative of the recipient. Transfers such as private households to businesses or governments, tax payments are classified as many-to-one transactions. [5]

Another way to classify payments is by the amount of currency transferred. For example, the transaction amounts of family expenses are many order of magnitudes smaller than the transaction amounts of pension fund managing assets of thousands of customers.

- **Large value payments:** Large value payments are usually between financial institutions. In addition, large value payments are usually time-critical. The number of these payments is relatively small, but because of their high value, their orderly settlement is essential for the proper and stable functioning of financial markets.

- **Retail payments are payments between non-financial institutions**: These are payments between private households, non-financial corporations or government agencies etc. There are normally large numbers of retail payments, but they have substantially lower average values than large value payments.

1.4 Classification of payment systems

Different models of payment systems have evolved to facilitate the payments between counterparties and to cater to their specific needs. However, payment systems can be broadly classified into two main categories: open loop systems, which connect intermediaries with different roles on a single platform, and closed loop systems, which connect consumers and merchants directly. A payment system also defines how value transfers are done and provides a framework of rules for the users of the system.

1.4.1 Open loop systems

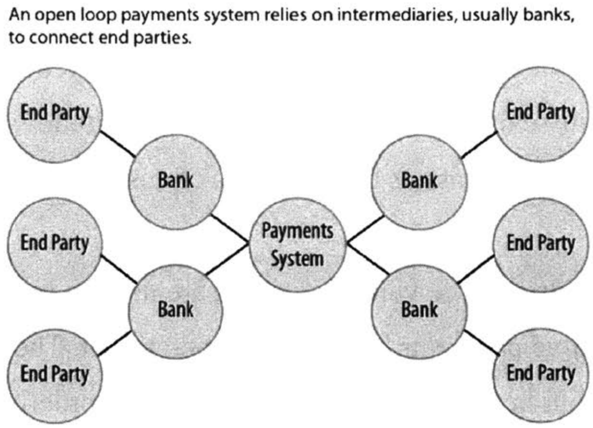

Figure 1: Open Loop Payment System[5]

Open loop systems operate on a hub-and-spoke model and almost all large-scale payment systems use this model. An open loop system requires intermediaries to join the payments system. These intermediaries then form business relationships with the end parties (for example, consumers and merchants). A transaction is passed from one end party to the bank, on to the network, on to the other end party's bank and then on to that end party. This structure allows the two end parties to transact with each other, without having immediate relationships with each other's banks.

The banks can also transact with each other without a direct relationship. The advantage of the open loop structure is that it allows a payments system to scale rapidly. As intermediaries join the network, all of their end party customers are accessible to other participants in the payments system.

1.4.2 Closed Loop Systems

A closed loop payments system operates without mediators. A single entity controls the complete network and the end parties directly join the system. Closed loop systems are simple. Since one entity sets all of the rules, it can act quickly. However, closed loop systems are more difficult to grow than open loop systems. Each end party must be individually signed up by the payments system.[5]

2 Payment systems in US

Cash, checks, credit cards, ACH (Automated Clearing House) and wire transfer systems are the core payment systems in the United States. The survey by the Federal Reserve Bank[6] shows an inverse relationship between the number and value of payments across the payment types. Debit cards have the largest share of payments by number, but smallest share by value. At the other end, ACH credit transfers held the smallest share by number but the largest share by value. Debit and credit transactions are primarily used for consumer-to-business (C2B) transactions, whereas ACH can be used for any type of transaction. Businesses are trying to move to ACH transactions, because they are very cheap compared to credit/debit transactions.

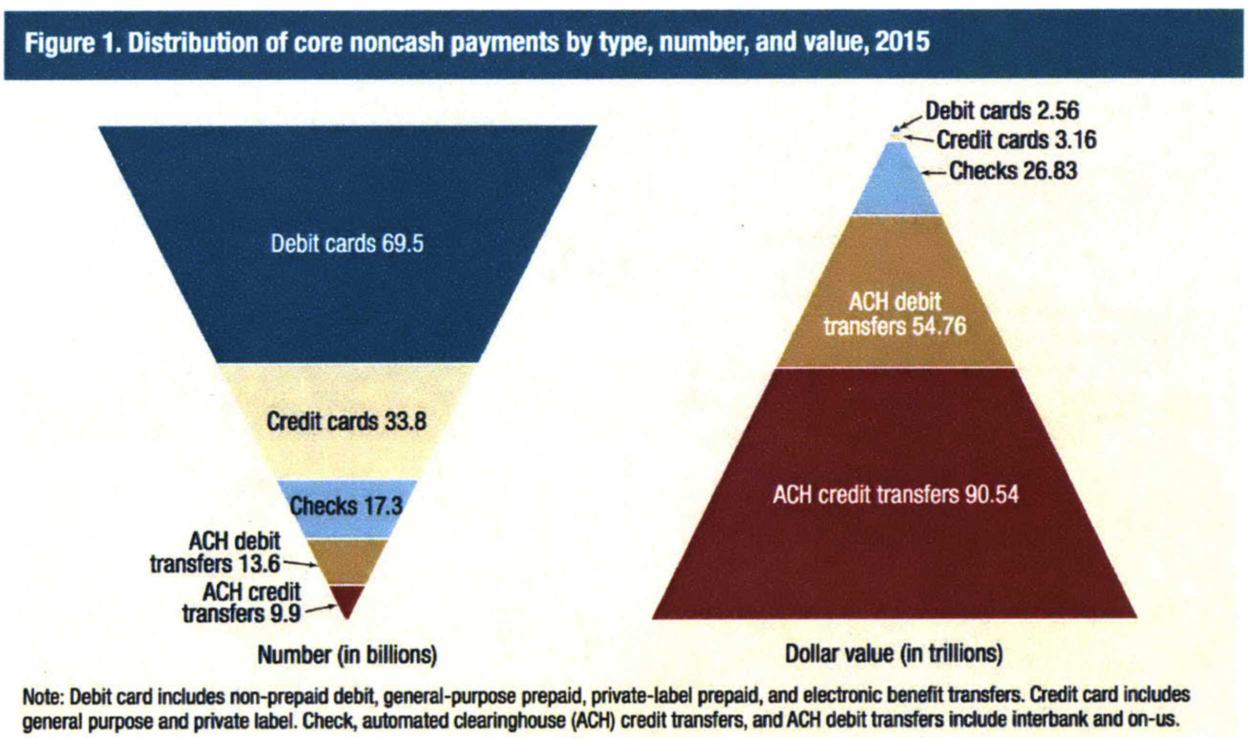

Figure 2: Distribution of core noncash payments[6]

2.1 Stakeholders

The highest level of the U.S. financial system has two main actors: the Federal Reserve system and commercial banks. The other entities are either regulators or utilities to enable transactions within the banking system.

The U.S. Federal Reserve system (Federal Reserve Board and Federal Reserve banks) is the central bank of United States. The system is divided in 12 districts, each with a separate reserve bank. The decentralized Federal Reserve System was established to overcome an "inelastic" currency stock and the concentration of the nation's bank reserves in New York City and other financial centers [7]. The Federal Reserve banks not only issue money but also provide payment services to facilitate transactions between financial institutions. The Federal Reserve System performs the following functions:

- Conduct the monetary policy
- Promote the stability of the financial system
- Promote the safety and soundness of financial institutions
- Facilitate payment and settlement systems for the banking industry
- Promote consumer protection [6]

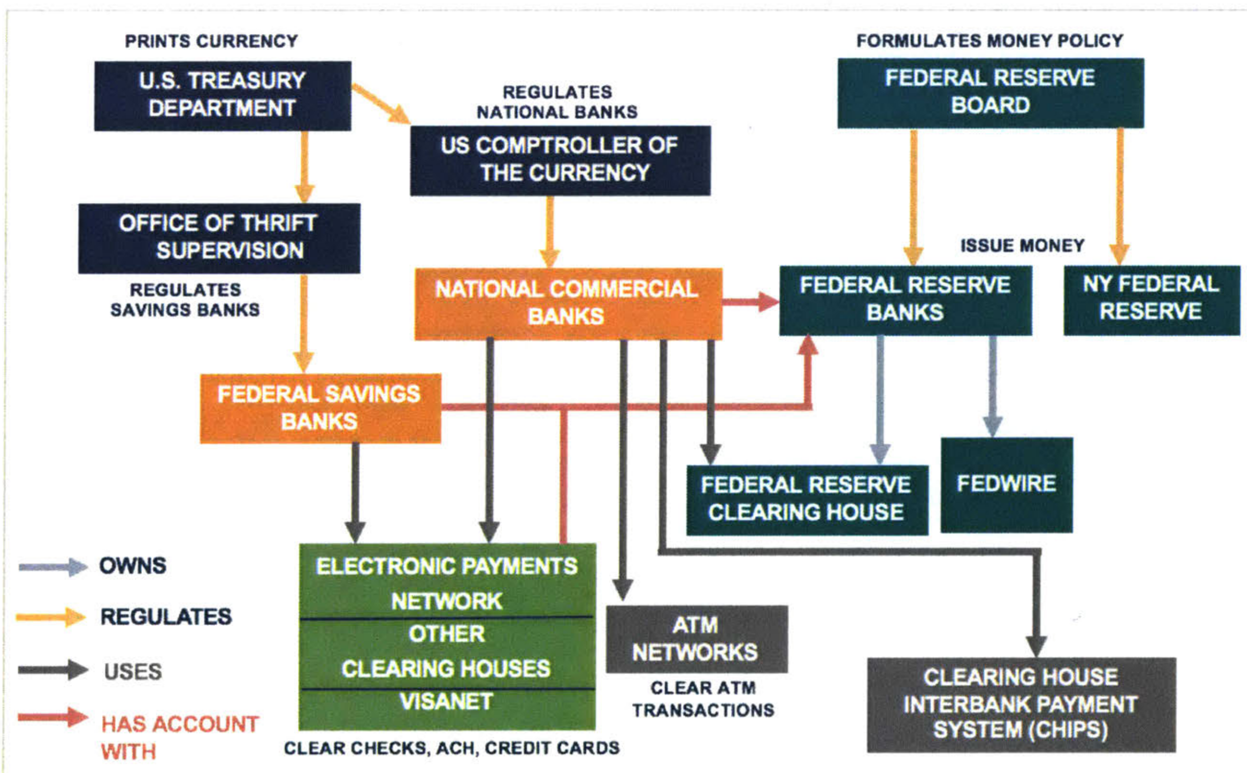

Figure 3: Stakeholders - U.S. Payment Systems

The U.S Treasury Department prints currency. The US Comptroller of the Currency and Office of Thrift Supervision regulate the national savings and commercial banks. Commercial and savings banks use electronic payment networks, clearing houses, ATM networks and credit card networks to provide payment services to customers. Together, these stakeholders enable the flow of currency in the economy.

Cash does not require any intermediary for transactions, but it does need to be printed and distributed. Checks, credit cards, ACH (Automated Clearing House) and wire transfers are payment systems which are enabled by different stakeholders. The next section describes the available payment systems in detail.

2.2 Cash

Cash is a bearer instrument with the ownership defined by possession. It is simple, convenient and anonymous. It is the simplest payment system from the consumer perspective. Anyone with a dollar bill can exchange the bill for goods and services. Cash is "permissionless" and censorship resistant. As a result, no personal information is required to hold cash and one can transact with anyone as necessary.

However, there is a cost for accepting cash as a payment. The cost of cash acceptance by merchants varies according to the type of merchant and the size of the cash payments. There are a few purely variable costs associated with cash: such as cash handling and depositing. However, the fraud (theft) control expenses are largely fixed. One result of this situation is that a merchant who slightly reduces the percentage of cash payments is unlikely to see a corresponding reduction in expenses.[8]

Cash is produced by the U.S. Treasury's Bureau of Engraving and Printing (notes) and the U.S. Mint (coins). Cash gets into the economy, when a bank with an account at the Federal Reserve Bank orders cash. The Federal Reserve Bank prints cash and earns the Seigniorage, which is the difference between the value and the cost of producing money. The bank then collects the cash and distributes it to bank branches, ATMs and merchants who have ordered cash.

Because cash is physical in nature, consumers need access to bank locations to deposit and withdraw cash. In the 1970s, banks introduced automated teller machines (ATM) to reduce branch operations expenses and to provide convenience to customers. ATMs allowed bank customers 24x7 access to their cash needs. Over the years, the ATM network has become highly interoperable, and the consumer can get cash from any ATM. [5]

Although consumers only interact with consumer banks for depositing and withdrawing cash, there are several providers in the industry which enable the cash transactions in economy.

- **ATM Manufacturers:** Banks do not manufacture the machines themselves. ATM manufacturers, suppliers and maintenance companies help banks to set up and maintain ATMs across the country.

- **Cash Delivery Services:** These service providers help banks to transfer funds between different locations. Since cash is a bearer instrument, it is inherently risky. Therefore, proper security is required when transporting cash.

- **Counterfeit Detection hardware:** Counterfeit cash is money printed without the permission of the central bank. Many security features are employed in notes and coins to prevent counterfeiting. However, nefarious actors still attempt to print currency and to circulate it in the economy. Special purpose hardware is required to detect and destroy counterfeit currency. Manufacturers develop and supply counterfeit detection hardware, which is deployed at cash collection points to monitor and prune out counterfeit currency.

2.3 Checks

Italian banks invented the "bill of exchange" around twelfth century. Banks issued a paper certificate that promised the recipient money from the bank. This enabled the traders to avoid carrying coins and currency over long distances and thus reduced the risk of theft. An important point is that the check was valuable because the possessors of the bills trusted that they would get the funds.[2] Consumers trusted cash because it was issued by the government, but with checks the trust shifted to banks. Check processing and handling used to be a manual process but has been updated with automated image processing based systems. Even with the availability of electronic payments and smartphones, checks are still widely used in the United States.

2.3.1 Payment Process

The checking system has four parties: the check writer, bank of check writer, recipient of the check and the bank to which the check is deposited. If the bank of the check writer and the bank of the recipient is the same, then the bank can just update the internal database and move funds between its customers.

However, if the check writer and recipient do not have an account in the same bank, the deposit bank has to deliver the check to the writer bank and receive funds for the customer. The early solution for transporting checks between banks was a common place where banks could exchange checks and settle transactions with each other. These places were the earliest forms of clearing houses. In the United States, the Fed operates the biggest check clearing service. Banks may send the checks for collection to another bank directly or use a local clearing house exchange or Fed Check collection services to settle the checks.

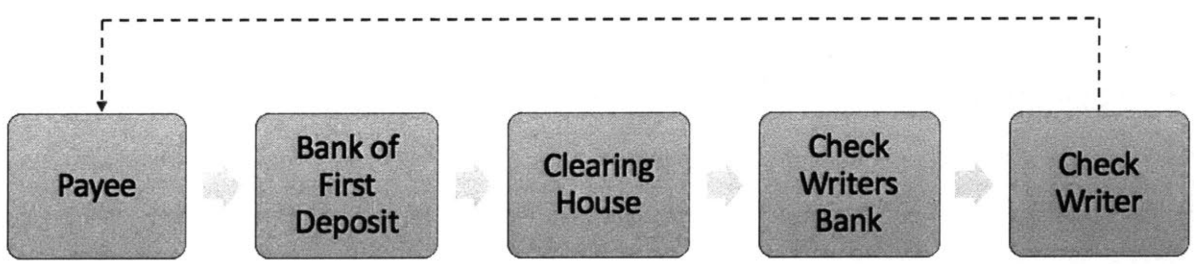

Figure 4: Check payment process[5]

At one point, the Federal Reserve Bank operated a fleet of airplanes just to transport the checks around the country. The Federal Reserve Bank has pushed the industry to adopt image based check clearing and settlement, so that the physical checks do not have to be transported to the banks across country. Banks are also adopting technology to convert the checks to an ACH transaction (a payment network operated by the Federal Reserve System).

2.3.2 Economics

Banks offer consumers and small businesses check writing and deposit capabilities as part of bundled "checking account" products. Writing or depositing individual checks is seldom separately priced. However, the customers have to purchase checks from the bank. Banks see check writing as an essential element of a package that brings deposits to the bank.

Banks do charge NSF (non-sufficient funds) fees for checks written on insufficient funds that the bank chooses not to return. This has historically been a significant source of bank revenue. As per a recent article in *The Wall Street Journal "Banks and other financial firms in 2016 generated the highest level of fees in seven years related to overdrafts on checking accounts, marking a turnaround for a charge crisis-era regulation that tried to rein it in. Overdraft fees totaled $33.3 billion in 2016, up about 2.5% from 2015 and by 5.4% from 2011".*[9]

Check use is declining in the U.S., but it is still a significant payment method. Unlike cash, the recipient and the writer must hold a bank account to use the checking service. Small independent businesses offer services to cash checks for the unbanked population. Independent shops which provide check cashing services to the unbanked, charge a very high premium to cash the check.

2.4 Automated Clearing House (ACH)

The National Automated Clearing House Association (NACHA) is a not for profit association representing about 10,000 financial institutions through 11 regional payment associations. NACHA operates the Automated Clearing House (ACH) network which uses batch processing to move almost $39 trillion and 22 billion electronic financial transactions each year. ACH supports direct deposit and direct payment transactions such as credit and debit transactions, recurring and one-time payments, government, consumer and B2B transactions, international payments and payment related-information.[10]

The ACH system was started in the 1970s by bankers working in check processing. With the introduction of check readers/ sorters, the entrepreneurs realized that all that was required to post transactions to customer accounts was the MICR. The magnetic ink character recognition code (MICR Code) is the technology used to process and clear checks. In the early days, ACH focused on high-volume, low-risk, repetitive transactions— particularly payroll checks, social security benefit checks and insurance premium payments. ACH is now wired to every demand deposit account in the country. An enterprise wishing to make or collect a payment using one of the ACH transaction types, can reach every banked consumer and enterprise in the country.

NACHA includes members in the process of establishing *Rules* for the ACH Network and works to create a clear picture of participant roles and responsibilities in the following ACH transaction process.[10] The following steps are involved in an ACH payment:

1. *An originator initiates a direct deposit or direct payment transaction using the ACH Network. ACH transactions can be either debit or credit payments and commonly include direct deposit of payroll, government and Social Security benefits, mortgage and bill payments, online banking payments, person-to-person (P2P) and business-to-business (B2B) payments.*

2. *ACH entries are entered and transmitted electronically, making transactions quicker, safer and easier.*

3. *The Originating Depository Financial institution (ODFI) enters the ACH entry at the request of the Originator.*

4. *The ODFI aggregates payments from customers and transmits them in batches at regular, predetermined intervals to an ACH Operator.*

5. *ACH Operators (two central clearing facilities: The Federal Reserve or The Clearing House) receive batches of ACH entries from the ODFI.*

6. *The ACH transactions are sorted and made available by the ACH Operator to the Receiving Depository Financial Institution (RDFI).*

7. *The Receiver's account is debited or credited by the RDFI, according to the type of ACH entry. Individuals, businesses and other entities can all be Receivers.*

8. *Each ACH credit transaction settles in one to two business days, and each debit transaction settles in just one business day.*

2.4.1 Economics

The ACH system was designed as a low-cost widely used utility for banks and their customers. The cost of using the ACH system and of providing the system is extremely low. There is no interchange in the ACH system, and no float or lending revenue is directly related to it.

Bank processing and clearing banks run ACH operations centers as cost centers that support multiple areas of the bank— for example, both the consumer accounts organization and the corporate payments organization might use the same ACH "engine."[5]

2.5 Credit cards

"Only the wealthy had payment cards in early 1950s; only the poor lack payment cards today. With the spread of payment cards, people can better coordinate their income and expenses, smooth income and consumption over their lifetime, and even more easily start and finance a small business."[2]

Credit cards have changed the way consumers spend money. They have pushed the market towards electronic payments. By creating the right incentives for everyone involved in the transaction, credit card networks have become ubiquitous. Credit cards use a four party model to process payments. The four entities are:

- **Cardholder**: an individual in possession of the card.
- **Issuer**: The bank or organization that issues the card to the cardholder.
- **Acquirer**: The bank which receives payment from the issuer on behalf of the merchant.
- **Merchant**: the entity which interacts with customers and receives the payment instructions and details from the cardholder.

2.5.1 Payment Process

Credit card payments are facilitated by private networks operated by companies such as Visa and MasterCard. The credit card and signature debit transactions are routed through the network twice— once in real time for authorization of the transaction and again (typically at the end of the day) for clearing and settlement. The card network processing hubs (Visa, MasterCard etc.) sit in the middle, receiving transactions from acquiring member banks (or, more often, from their processors), sorting and switching them to issuing banks and processors. The authorization transaction is in real time, with sub-second response times. The clearing and settlement transaction happens in batches, typically at the end of the day when the store closes. The payment process from a cardholder to the merchant is illustrated below:

- Customer goes to the Best Buy store to buy a new music player and wants to use your Visa card issued by Bank of America (the "issuer").

- The card reader takes data off of the magnetic stripe on the back of the card. It combines this data with information about the merchant and the dollar value of the purchase to create an electronic message.

- The card reader then dials the telephone number of a server maintained by the merchant's acquirer (the bank that handles transactions for the merchant). Once connected, a message is sent through to the acquirer's servers.

- The acquirer's server reads the message and figures out that the customer has used a Visa card. The acquirer then forwards the message to the Visa servers.

- After reading the message, Visa knows to check with Bank of America to see whether customer has enough money in their credit line to secure the purchase.

- If the customer has the enough money, Bank of America will send a message back to Visa. The transaction is thus authorized.

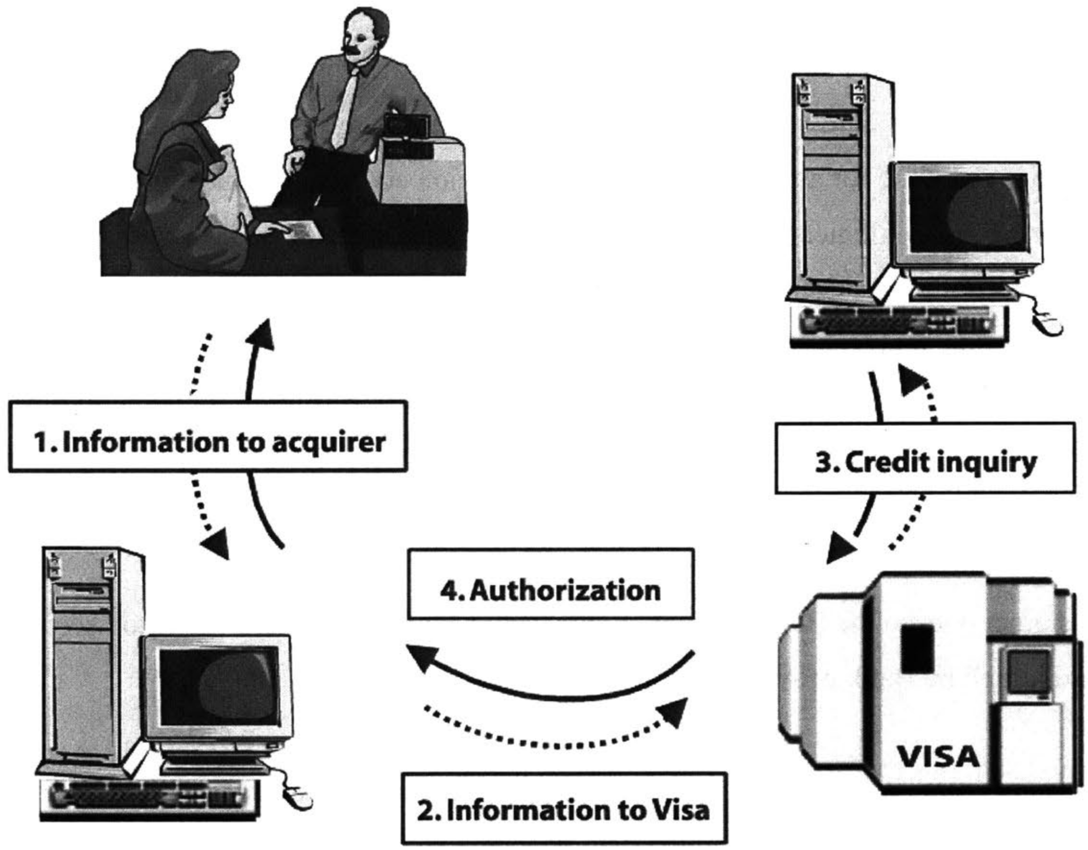

Figure 5: Credit card payment process[2]

- Visa relays the message back to the store's acquirer, who then sends a message back to the terminal at the store. The terminal prints out the receipt that the customer signs.

- The store then submits a request for payment to its acquirer that, in turn, sends it on to Visa. Visa passes on the request to Bank of America, which posts the transaction to the customer's account.

- The Visa computer consolidates this transaction with all of the other Visa transactions and settles accounts among banks.

- For this purchase, Bank of America pays the acquirer, who then pays the BestBuy store. This process is typically completed within two to three days, from the time customer made the purchase.

- The BestBuy store actually receives only about 98 percent of the amount charged for the music player. The remaining 2 percent difference is called the "merchant discount," which is the fee paid to the acquirer for providing its services.

- The acquirer, in turn, pays about 1.4 percent of the purchase amount to the issuer, in this case Bank of America. That 1.4 percent is called the "interchange fee" and is set by Visa. [2], [5]

2.5.2 Economics

Merchants benefit the most by accepting cards, as card payment makes it easier for customers to pay. Issuers, however, bear the cost and the risk of payment from the customer. Card networks established an interchange fee to have the value-receiving merchant compensate the cost-incurring issuer for some of the issuer's expenses. The network, by defining the appropriate cost reimbursement between the parties, made the economics work.

The credit card issuer incurs the following costs for offering guarantee of payments and for paying the merchant before it gets paid by the customer:

- **Cost of guarantee:** The card issuer is extending a payment guarantee to the merchant—the merchant is paid, even if the cardholder subsequently fails to pay the card issuer what he or she owes.

- **Cost of funds**: The merchant receives payment from the issuing bank (via the card network), before the issuing bank is paid by the cardholder.

- **Operating expenses**: The issuing bank has expenses in operating its authorization network, producing statements, handling customer service, etc.

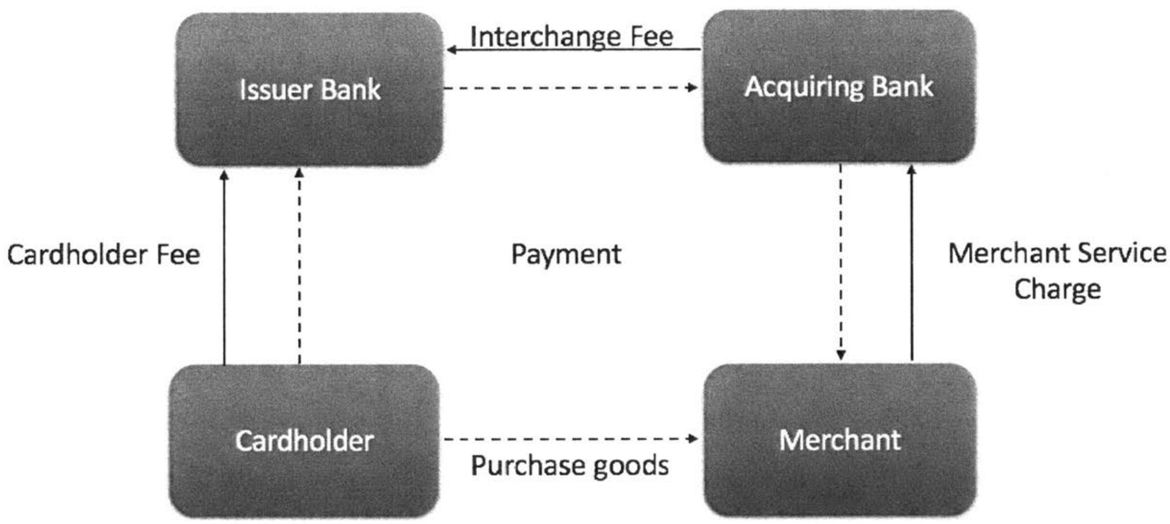

Figure 6: Credit card fee exchange[2]

The fee structure of credit cards provides the right incentives for everyone to encourage credit card use. Each card transaction involves two banks with interchange being a fee that one bank pays to the other as compensation for some of its costs. The network sets the interchange fee and determines the direction of payment. In the United States, interchange flows from the acquiring bank to the issuing bank on purchase transactions. The acquiring bank passes this interchange expense along to its customer, the merchant. The acquiring bank's fee to the merchant is known as the "merchant discount fee," of which interchange is the largest single component.[5]

2.6 Wire transfer systems

Wire transfer systems carry the serious money in the U.S. payments systems. Also known as "large-value systems," the U.S. wire transfer systems, and their counterparts throughout the world, are designed to handle very high-value transactions between businesses, and most often between financial institutions. Wire transfer systems settle each transaction individually as it occurs, and this gross settlement is necessary to avoid the risk associated with bank failure. These systems have very low volume, but transfer a large percentage of the dollar value. The United States has two systems for wire transfer: FedWire and CHIPS.

2.6.1 FedWire

"Fedwire is a real-time, gross-settlement system that enables you to send or receive payments for your own account or on behalf of clients, settle commercial payments or positions with other financial institutions or clearing arrangements, submit federal tax payments or buy and sell federal funds." [11]

Fedwire is available to banks that have an account at one of the Federal Reserve Banks. The Federal Reserve Bank acts as an intermediary to facilitate transactions between the bank customers. As an example, an enterprise that wants to transfer money sends a message to its bank. The bank debits the account and sends a message to Fedwire. The Federal Reserve Bank debits the bank's account and credits the account of the receiving bank. The receiving bank then credits the account of the receiving company. All of this is done online, in real time. The electronic messaging is done with a high degree of security.

The core management problem for all value chain participants is risk. Before sending the instructions to the Fed, the sending bank must be absolutely sure that there are sufficient funds in its customer's account. Before crediting the receiving bank, the Fed must be certain that there are good funds in the bank's account. Thousands of transactions and millions of dollars flow instantaneously through these systems, and it is critically important to avoid mistakes. Many companies decide to have wire transfers subject to dual internal approvals.

Most international wire transfers moving to and from United States pass through one of New York's money center banks. On average about 80,000 transactions (worth nearly $500 billion) pass through the wire transfer of Citibank alone. There is a high rate of error in wire transfers. Only about seventy percent of the transactions are shunted directly to FedWire. The other thirty percent must be "repaired" i.e. an operator manually edits the request and submits it for processing. [12]

2.6.2 CHIPS

The Clearing House Interbank Payments system (CHIPS) is a private sector alternative to Fedwire. CHIPS is owned by The Clearing House, which is owned by large banks in the United States. It is similar to Fedwire in that it is a real-time, fully guaranteed system that is meant to handle high-value payments. CHIPS is used by only a small number of very large banks. It has 59 members, including large U.S. banks and U.S. branches of foreign banks.[13]

"CHIPS is an electronic payments system that transfers funds, settles transactions and provides intraday payment finality through a real-time system. CHIPS settles small payments, which can be accommodated by the banks' available balances, individually. Other payments are netted bilaterally (such as when Bank A has to pay $500 million to Bank B, and Bank B has to pay $500 million to Bank A), without any actual movement of funds between CHIPS participants." [13]

Each participant funds its CHIPS account by depositing a certain amount between 12:30 and 9:00 a.m. This "security deposit" is recalculated weekly and is set by CHIPS based on the number and size of the bank's recent CHIPS transactions. At the end of the day, CHIPS uses these deposits to settle any unsettled transactions.

2.7 Mobile payments

The growth in smartphones has pushed the limits of consumer experience. The possibilities are limitless, when everyone has a computer connected to the internet in hand. Therefore, many companies are trying to enable and capture payments using smartphones. Two business models have emerged to facilitate delivery of financial services through mobile phones - mobile wallets and closed loop mobile money services.

2.7.1 Mobile Wallet

A mobile wallet is essentially an application which allows consumers to use their phones for local and remote transactions. According to JP Morgan and Chase:

"Mobile wallets are essentially digital versions of traditional wallets that someone would carry in their pocket. While there are many variations, usually they can hold digital information about credit and debit cards for making payments, store coupons and loyalty programs, specific information about personal identity and more." [14]

It is important to note that the consumer still utilizes the pre-established relationship with the financial institutions (such as bank and credit cards) to pay for goods and services. Therefore, instead of swiping a credit card at the Point of Sale, the consumer uses NFC technology in the smartphone to transmit the card details etc. on the network.

However, consumers can benefit from mobile wallets because it allows them to digitally hold all of their card payment information, loyalty programs, etc. in a single application. Financial institutions can provide added value to customers through marketing, loyalty programs, on demand financial services etc.

Apple Pay and Google Wallet are examples of mobile wallets, which are services to improve the user experience of existing payment systems. Robleh Ali, John Barrdear, Roger Clews and James Southgate define wrapper services as:

"This category of innovation focuses on providing 'wrapper' services to improve the user interface and accessibility of existing payment systems architecture. These innovations therefore represent neither a new currency nor a new core payments system. The core motivation can be either new entrants seeking to capture a segment of the market, or incumbents seeking to improve market share and reduce consumer use of other, more expensive payment systems. Examples include Google Wallet, Apple Pay and Paym, which builds on the existing infrastructure to make payments by linking users' mobile phone numbers to their bank accounts. [15]"

2.7.2 Closed loop mobile money system

M-PESA is the largest closed loop mobile money system in the world. It lets people transfer cash using their phones. M-Pesa was launched in 2007 by Safaricom, a mobile-network operator, in

Kenya. It is now used by over two-thirds of the adult population in Kenya and around 25% of the country's gross national product flows through it.

M-Pesa is a closed loop system which allows people to make transactions. Once a customer has signed up, he pays money into the system by handing cash to one of Safaricom's 40,000 agents[16], who credits the money to the M-PESA account. Because it is a closed loop system, the transfer of money from one customer to another is just a database update that credits the payee and debits the payer. Dozens of mobile-money systems have been launched around the world to replicate the M-Pesa model. Venmo and Circle are two companies trying to capture this market in U.S.

2.8 U.S. compared to the rest of the world

Overall, the U.S. payment systems are highly fragmented and outdated. The advances in computing allow for real time payments and settlements, and most advanced countries now have sophisticated real time gross settlement (RTGS) systems which allow instantaneous settlement. More than 16 countries including Brazil, China, Korea, Switzerland and the UK have real time payment systems for the public. India has multiple systems in place and Singapore payment systems can process payments in multiple currencies.[17] The U.S, has no capability to perform real time money transfer transactions for business – to – business (B2B) or consumer – to – business (C2B) needs.

The credit card networks are fairly similar everywhere. The U.S. has kept pace with the advancements in technology. However, one of the main payment systems, ACH, has some major problems. The key shortcomings of ACH are:

- **Settlement time**: Traditionally, ACH took one to two days for the settlement of funds. However, NACHA has recently introduced a system to offer same day processing of ACH credit transactions and will start offering same day debit transactions by the end of 2017[18]. One-day settlement time for credit transactions is very well received in the industry. An increasing number of transactions are moving online and if consumers are able to spend 24x7, payment systems that allow real time settlement would bring huge liquidity gains for the businesses.

- **Batch Processing**: ACH handles major transactions such as payroll, supplier payments, state taxes, bill pay, urgent claims/refunds, person-to-person, account-to-account, check conversions and collections. However, the current system still uses batch processing and requires users to submit payments by specific cutoff times. Even with same day processing, ACH would enforce cut off times to receive files.

- **Risk Management:** ACH risk is comprised of operational risk, fraud risk and credit risk. ACH processing is a penny business for banks. There is no pricing for risk and it costs a few cents to send a transaction, whether it is for fifty dollars or five million dollars. Per transaction pricing is extremely low and it is almost impossible for a bank to make real money or even an acceptable return on their expenses in ACH processing without very large volumes.

3 Payment systems analysis and comparison

Payment systems are complex because the main goal is to enable transactions between all members of the society. They have inherent risks, which need to be managed. It is also difficult to launch a new payment system, since the success depends on network effects. This chapter details the parameters to evaluate payment systems, the risks involved in payment systems and the factors that drive the adoption of new payment systems.

3.1 Evaluation of payment systems

A payment system can be evaluated from four dimensions: technical aspects, economic aspects, social aspects and regulatory aspects[19].

3.1.1 Technical Aspects

The technical aspects of a payment system include its robustness, expandability, security and compatibility with other payment systems. Financial activities require secure transactions and the payment system must satisfy the following requirements:

- Identity Management: This is one of the biggest concerns for an electronic payment system. The payment system needs to verify the identities of the parties involved in the transaction in order to prevent fraud.
- Privacy: This is the ability to protect the anonymity of the purchaser in the transaction and to prevent unauthorized personnel from accessing the records. It is one of the main benefits of cash. The bearer can use cash wherever one wishes.
- Accuracy: This is also known as immutability. It is the measurement of the payment system's ability to restrict changes to the transaction data.
- Atomic transactions: An atomic transaction means that either everything occurs or nothing happens. The credits and debits must happen together.

3.1.2 Economic Aspects

A payment system would only be used if it is economically viable. The cost of building, maintaining, running and upgrading the payment system is a critical parameter. The economic needs can be summarized as:

- Cost of transaction: This refers to the cost incurred by the seller and buyer in performing the transaction. The cost includes both direct and indirect costs.
- User Reach: This refers to accessibility of the payment system. This attribute defines whether the system is accessible to all countries, age groups etc. A payment system is only valuable, if one is able to pay the desired payee.
- Financial Risk: Consumers are always concerned about the risks involved in the transaction. It involves the potential losses that customers or merchants can incur by using the payment system.
- Charge backs: This is the ability of the payment system to reverse the transactions.

3.1.3 Social aspects

In addition to technical and economic aspects, a payment system needs to address the social needs of consumers. The needs include:

- Anonymity: the ability of the payment system to allow anonymous transactions
- User friendliness: Simplicity is critical in payment systems. This is one of the key factors in the development of new payment methods.
- Accessibility: This is the ability of payment to be used in wide variety of payment scenarios.

3.1.4 Regulatory Aspects

A payment system moves money between people and each country and jurisdiction has its own policies. The payment system should be able to conform to the regulations of the geography it is accessible from.

3.2 Risks in payment systems

All systems related to money are exposed to risks. In payment, clearing and settlement systems, participants face the risk that settlement in the system will not take place as expected. This usually occurs because of a party defaulting on one or more settlement obligations. This "settlement risk" includes credit risk, liquidity risk, operational risk and legal risk. Payment systems that are capable of generating domino effect and that can cause issues for the whole economy are called systemically important payment systems (SIPS).

The participants in the payment system, therefore, face risks from transacting with customers and also in their transactions with other participants in the payment system. It is important to note the difference in risk associated in "open loop systems" and "closed loop systems". Since closed loop systems do not interact with other counterparties, they do not face the risk associated with participants in the payment system.

- **Fraud Risk**: This is risk resulting from the use of financial instruments without genuine authorization by the owner of the financial instrument. It is an increasing concern in online e-commerce websites, since it is tough to prove that the person entering the information is actually the owner.

- **Credit risk**: It is the risk that a counterparty will not settle (i.e. discharge) an obligation for full value. It can happen from the extension of any form of unsecured credit or from a failure to synchronize the various interrelated elements (or "legs") of a transaction. For example, in interbank payments, payment data may be exchanged directly between banks and with funds credited to receiving customers, before interbank settlement is complete. The credit risk involved in net settlement systems is often controlled by:

    - Increasing the frequency of net settlement cycles during the day
    - Setting upper limits on the size of individual payments
    - Limiting the membership to counterparties that are considered least likely to default on a settlement obligation.

- **Systemic risk**: The risk that the inability of one participant to pay in a system, will cause other participants to be unable to fulfil their obligations when they become due.[3]

3.2.1 Risk Management

There are two main methods of support for risk management: technology and statistical analysis. The aim of risk management is to identify the fraud before authorizing the transaction. This is possible for electronic payment systems, but it is still a huge bottleneck for check payments. When a payer writes a check to payee, the payee has no way to check if the payer actually has funds in the account. Technology has enabled many techniques to manage risks.

Technology

Technology enables the capture and association of information of each financial instrument and/or customer. Information such as geo-location, the IP address or the device and the history of the payer's previous transactions with the retailer or the digital wallet, can help to predict the authenticity of the transaction.

However, technology also increases complexity. Multiple layers of processing or independent systems that pass information between each other, means there are multiple potential points of failure. Each component needs to have adequate measures of protection.

Statistical Analysis

Statistical Analysis leverages the information that the technical platform collects as well as various behavioral aspects of a buyer and seller. Statistical models and neural networks have made a significant impact in the payments space. The most recent trend has been the use of machine learning algorithms and big data to study patterns and draw inferences. It is now common for credit cards to block the payment, if the card is used at a location which is significantly different from the usual location.

Continuous Risk analysis

Risk is not just a point in time decision. It is a lifecycle analysis of the buyer and seller. The combination of technology and statistical analysis is used through the life of a user's alliance with a credit card company or a digital wallet provider, to continuously update and predict the risk factors. Risk evaluation is done at the time of sign up to ensure that the consumer is authentic.

Subsequently, at the time of transactions, there are live evaluations that allow some transactions to go through and to abort others.[20]

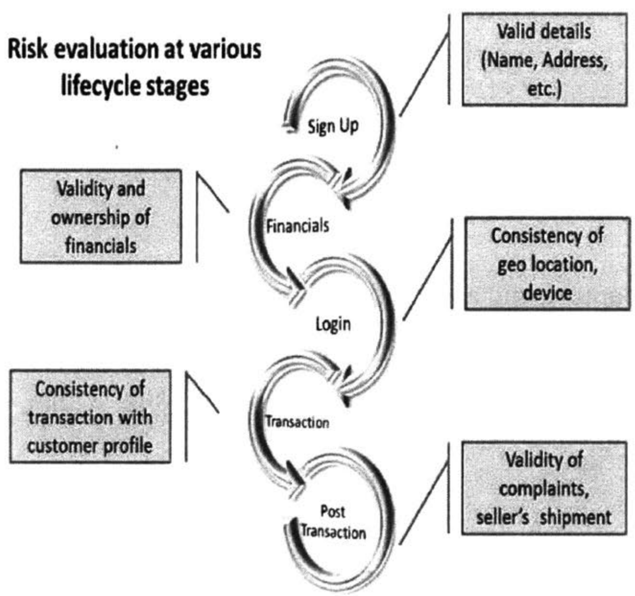

Figure 7: Risk evaluation at various lifecycle stage[20]

3.3 Drivers for success of payment systems

An electronic payment system is enabled by various stakeholders which are systematically arranged by some pre-determined rules. Customers and merchants are also stakeholders, since they are affected by the payment system. Stakeholders have different roles and interests which affect the success of the electronic payment systems. The success of a new payment system heavily depends upon gaining the right network effects. An example is a payment system that becomes more valuable, as more participants use it. The cost to stakeholders should also justify switching to a new payment system. The two factors are detailed below:

- **Mutuality of costs and benefit of the system**: It is necessary for all stakeholders that the costs incurred from using the system, should be justified by the benefits obtained by that stakeholder. Without stakeholder mutuality, it is unlikely that an electronic payment system will be widely adopted.

The principal motivation of a central bank to offer a payment system to commercial banks is to promote financial stability. Access to robust payment systems is crucial to enable a wider and tailored range of financial services used in society. Extending access to financial services, is thus the first building block for people to build a better life. Not only does it help individuals plan for long term goals and emergencies, it also yields benefits that go beyond individuals in the form of reduced inequality and accelerated growth. World Bank Group President, Dr. Jim Yong Kim, has set a Universal Financial Access 2020 (UFA 2020) Global Goal: "By 2020, adults globally have access to an account or electronic instrument to store money, send and receive payments as the basic building block to manage their financial lives." [4]

One of the main factors in the exponential growth of credit card use was the correct incentives that the service offers to the stakeholders to use the card. By offering credit cards, banks gain new customers, merchants get an easy way to collect money and consumers are lured with reward programs to adopt credit cards.

- **Network Effect**: The success of a payment system depends on the ability to reach a critical mass of system users and merchants.[21] The perceived benefit of a system is low, when there are few users. After a certain level of adoption, the benefits of use increase at a rapid rate and the system use accelerates until saturation is achieved.

  BankAmericard leveraged this effect to introduce credit cards in California. It mailed free credit cards to more than sixty thousand customers in California. The merchants were attracted to credit cards when they realized that so many people could use the new form of payment[2].

3.4 Future of payments

Payment systems are moving from being a channel for transferring funds to a much wider integrated network for transferring additional forms of value. The conception of channels for retail payments can have a substantial role in supporting financial access in developing countries. A well-functioning foundation to efficiently and safely process modern payment instruments is necessary to enhance a country's population access to such modern payment instruments. [20]

- **Faster Payments:** Even though most countries have systems that allow immediate settlement of high value payments, the systems that handle low value transactions have settlement times that can take days. Many countries are now investing in immediate payment services (IMPS), which would allow instant settlement of payments. With the growth in e-commerce and digital business, immediate settlement would be a norm rather than an exception.

- **Anytime Payments:** Globalization and e-commerce have equipped businesses to accept orders 24 hours a day and 365 days a year. However, the core payment system in the U.S., ACH, does not operate on weekends. Electronic payment systems will very soon enable transactions around the clock.

- **Increase in small value payments**: According to the Federal Reserve Payments Study 2016, debit cards held the largest share of payments by number but the smallest share by value. This trend of increases in small value payments is expected to continue to grow, although the payment medium might not necessarily be debit cards. The growth of services such as Venmo, which facilitates peer to peer value transfer, and Apple Pay, which enables mobile payments by consumers would have network effects and grow the popularity of digital payments. WeChat Pay and Alipay already have more than 400 million users and the growth is expected to continue.

  The increase in small ticket size transactions would need a robust payment platform which is able to grow with the increase in the number of transactions.

- **Proxy systems to connect digital identities with bank accounts**: The existing payment platforms are built for transactions between account numbers (bank account, credit card numbers etc.). Since individuals now have many digital identities, such as email addresses, Facebook IDs etc., many new payment systems enable the users to pay using these IDs.

Singapore has developed a proxy system to collate all IDs into one system and to allow payment without exchanging account numbers.

- **Seamless Payment API integration:** e-commerce continues to grow every year. Payment is just one of the aspect of the user experience online. 'one-click' Amazon ordering and the seamless Uber process for booking and paying for a car ride are examples of a payment process that is well integrated in the purchase experience. Payment APIs designed as a platform for integration into complex transaction flows will enable businesses to a build good user experience and would provide value beyond simply moving money.

- **Increased security as speed of payments increases**: the speed of payment makes fast payments makes a target for fraud. Criminals target fast payment systems because, if successful, they can abscond with funds immediately. As the speed of payments increases, the need for better fraud detection would increase.

  Visa, MasterCard and most of the large banks already apply machine learning and neural Network techniques for fraud detection. Nevertheless, in 2016 for every $100 in volume, 6.97 cents were fraudulent, up from 6.21 cents per $100 in 2014. By 2020, card fraud worldwide is expected to total $31.67 billion. The U.S. accounted for 38.7%, or $8.45 billion, of gross card fraud losses, while generating only 22.9% of total global purchases and cash volume.[22] There is considerable for improvement. The AML and fraud detection capabilities would be the key value propositions of the payment providers.

- **Continued focus on risk, regulation and compliance for detection of suspicious activity**: Payment companies have to make a considerable effort in compliance and risk management. Transfers that seem harmless when viewed by a single financial institution, can be identified as part of a complex web of transactions at the network level. Inter-bank payment systems are increasingly taking steps to monitor network traffic to identify potential criminal activity. As micro payments become more affordable, the need to detect fraudulent transactions is expected to continue to increase. [23]

4 Motivation to adopt distributed ledger technology for payments

4.1 Overview

Banks were early adopters of technology, and the advancements in technology affected the payment systems in two ways.

First, the records and accounting maintained at banks were converted from paper to electronic. In the era of paper based accounting, banks had to physically meet at a central place to settle the transactions. Until very recently, the Fed owned a fleet of airplanes to transport the checks around the country. Almost all of the physical movement of checks and ledgers has been now replaced by electronic messaging systems. However, the current electronic systems, replicate the processes done without technology. Every bank or counterparty maintains its own ledgers, communicates via a central hub and then each counterparty performs reconciliations to confirm that the transactions were performed accurately. The systems are largely designed to operate in batches, and thus do not offer real-time settlements.

Second, the emergence of e-commerce and the ubiquitous availability of mobile devices opened a door for the introduction of new payment methods. The need of accepting payments online led to the emergence of services such as PayPal and Stripe, which enabled merchants to accept payments online. Mobile devices prompted telecommunication networks and device manufacturers to offer payment options to consumers [15]. Despite the new offerings and new payment methods, the basic structure of centralized payments has remained the same. The final clearing and settlement is still done using the centralized payment rails.

The emergence of digital currencies, such as Bitcoin and the underlying technology Blockchain, have prompted a discussion of whether the banks should utilize the distributed ledger technology.

In this chapter, I explain the paradigm change offered by Blockchain and explore the reasons why the central bank or commercial banks could use the new technology offerings to either facilitate the use of digital currency or to improve the infrastructure.

4.2 Bitcoin and the new paradigm of distributed ledgers

Bitcoin, introduced in 2009, is the largest functioning digital currency. The underlying technology, Blockchain, offers a paradigm change for processing payments between counterparties connected over a network. The Blockchain is essentially a 'distributed ledger' that allows transactions in a decentralized way. Every counterparty attached to the distributed ledger has full view of the accounting and can independently verify the transactions. To make a payment, the user sends the payment instructions to the network. Cryptographic techniques embedded in the protocol enable network participants to check and confirm the transaction. Therefore, the network works as one single entity and affirms transactions. No single entity is the in charge of the system, and any new participant willing to contribute computing power can join the network.

On the other hand, digital payment transactions in existing systems are facilitated by intermediaries. The mediators maintain their private ledger of account balances, verify the payment details and transfer the funds between counterparties. All accounts are legally in the books of a given service provider, who is in charge of booking transfers and reconciling the ledger. A central bank is in charge of the accounts in its ledger, and a commercial bank is in charge of the accounts in its ledger. Interbank settlement books are used to facilitate transfers between ledgers of different service providers. The old payment systems, therefore, consist of large networks of individual centralized account ledgers connected via an inter-ledger settlement function to enable transfers between different ledgers.

The brokers in the payment system thus incur "networking cost" and "verification cost." Networking cost is the cost of connecting the independent ledgers for performing operations and verification cost is the cost of maintaining reputation systems that verify the transaction details and cost of reconciling the databases to resolve errors.[24]

Internet stashed the cost of running centralized networks, as it allowed entities to connect to each other through inexpensive networks. Now, Blockchain has the potential to reduce the "networking cost" of running decentralized systems as well as the "verification cost" for the entities involved in a transaction. Blockchain allows the transaction details to be stored on a shared network. It enables a consistent and verified view of events to all counterparties involved in providing payment services. Thus, the audit capabilities can be embedded in the network. Anyone on the network can perform an audit at zero cost.

As Christian Catalini and Joshua S. Gans explain in Some Simple Economics of the Blockchain "*On a blockchain, it is cheap to verify the integrity of an individual transaction or its attributes, i.e. not only a single piece of information can be audited in real time, but its integrity is available to any participant in the network. As a result, verification can be economically implemented at a substantially more fine-grained level than before. For example, accounting information can be built up, with integrity, from the most simple units of transactions, making it substantially more costly to alter a ledger (e.g. voting machines, accounting records etc). What previously constituted a time consuming and costly audit, is now a process that can run continuously in the background to ensure market safety and compliance, lowering the risk of moral hazard.*"[24]

This far-reaching decline in cost challenges existing revenue models and shatters the barriers to entry for new payment systems to emerge. A decentralized payment infrastructure opens opportunities for novel approaches to conduct transactions and to regulate.

However, rather than thinking about a technology push, it is useful to look at the issue from the holistic thinking principle of system architecture. It is important to consider the goals of The Fed and commercial banks to understand why they might choose to use the new technology[25]. In the next section, I mention possible goals that The Fed or commercial banks might achieve with the distributed ledgers.

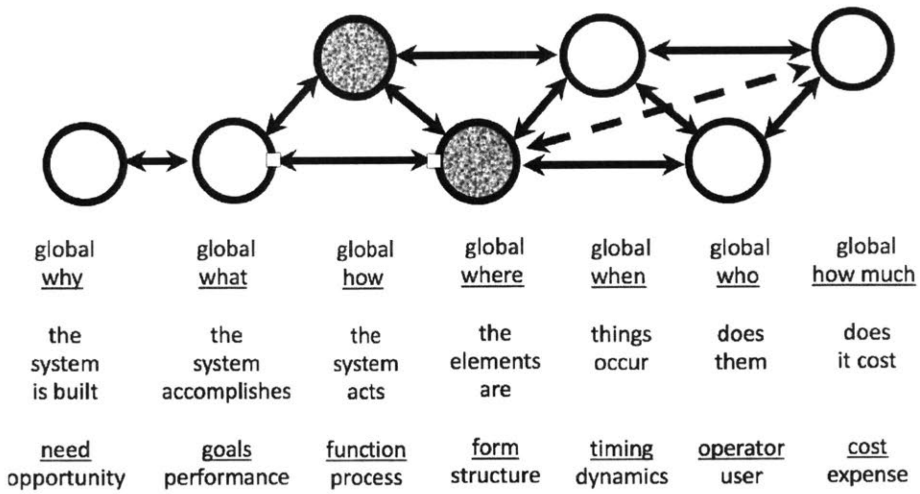

Figure 8: System architecture process[25]

4.3 Why the Federal Reserve Bank might use a distributed ledger

The Federal Reserve banking system has five functions: conduct the monetary policy, to promote the stability of the financial system, to promote the safety and soundness of financial institutions, to facilitate payment and settlement systems for the banking industry and to promote consumer protection. The availability of an alternative currency that is not controlled by the Federal Reserve banking system is not only a threat to existence of the federal bank but also a threat to the safety and soundness of the financial institutions. It is, therefore, natural that the Fed is already spending a considerable effort in developing an understanding of the new technology.

Based on the current functions of The Fed, the goals of leveraging Blockchain technology could be: to compete with new digital currencies, to control the KYC and AML, to provide a banking option to the unbanked and to provide ubiquitous payment services to all.

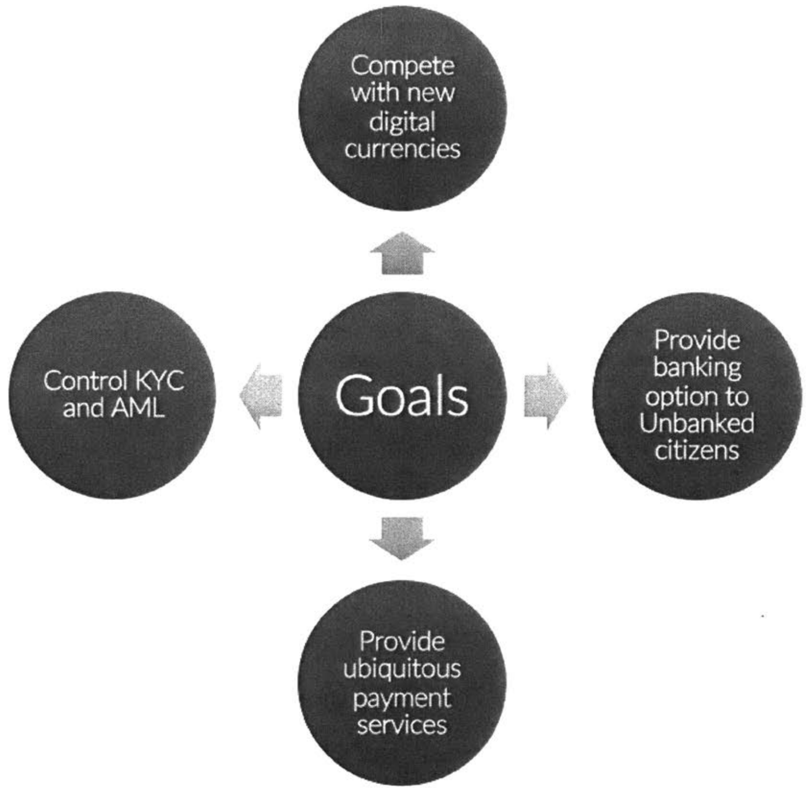

Figure 9: Potential Goals of U.S. Federal Reserve Bank

4.3.1 To Maintain relevance and to compete with new digital currencies

An autonomous digital currency, such as Bitcoin, in an economy, competes with the official currency issued by the country's central bank. Competition between the official currency and private money is not new. In many countries alternative money has included commodities such as gold, silver and other goods that have served as stores of value and media of exchange. India, for example, has suffered from economic problems because people tend to buy gold in large part due to its cherished status in marriage ceremonies.

For a central bank, the challenges posed by a digital currency are the same as those posed by the presence of a competing foreign currency or any other alternative store of value[26]. Any store of value that makes it difficult for the Fed to execute monetary policy is a threat to the existence of the central banking system. The price of a currency is determined by the relative supply and demand of the competitive currencies. Historically, central banks were the only suppliers of currency, but digital currencies threaten that position.

On the other hand, consumers of currency benefit from competition between different currencies since the presence of multiple currencies gives them flexibility to choose settlement terms. From the point of view of consumers of money, competition in the provision of money is a check on the behavior of the supplier.

The central bank could consider offering a digital currency as an alternative store of value for the public. Unbanked or banked customers who do not have trust in the commercial banks, would opt for a central bank issued digital currency. Other advantages to the central bank having its own digital currency would be to give the government more control and understanding of the financial system. This control would facilitate better intervention in business cycles and improved market response.

4.3.2 To provide banking option to Unbanked citizens

The Federal Reserve system of the United States conducts monetary policy, regulates banks and maintains stability of the financial system by containing systemic risks that might arise in the market and overseeing the nation's payment systems [27].

The banking sector, on the other hand, facilitates the savings and investments in the economy. The banking system assembles the scattered savings and makes them available to use for investments. Inclusion in the financial system enables households to manage their funds effectively and to invest for the future. However, according to the latest FDIC survey in 2015 [28], 7.0 percent of U.S. households were "unbanked," meaning that no one in the household had a checking or savings account. Therefore, approximately 9.0 million U.S. households, consisting of 15.6 million adults and 7.6 million children, were unbanked.

The 2015 survey asked unbanked households about the reasons for not having an account. The most commonly cited reason was "Do not have enough money to keep in an account." An estimated 57.4 percent of unbanked households cited this as a reason, with 37.8 percent identifying it as the main reason. Some of the other main reasons were "Don't trust banks" (10.9 percent) and "Bank account fees are too high" (9.4 percent).[28]

- The unbanked customers are, therefore, the left out citizens who are caught in a catch-22 situation. They are the ones who are most in need of credit. However, no bank will offer them credit since they do not have any savings.

In a March 2016 speech, Ben Broadbent, Deputy Governor for Monetary Policy at the Bank of England, discussed the idea of a central bank digital currency involving a distributed Bitcoin-style Blockchain containing reserve deposits issued by the Bank of England. Broadbent said

"it seems likely that a distributed ledger would make that process easier, opening up the balance sheet to a wider variety of financial firms. One might go further, giving access to non-financial firms, or perhaps even individual households. In the limit, a distributed ledger might mean that we could all of us hold such balances"

Digital currencies could provide a much cheaper way to offer banking services to the unbanked. Since commercial banks do not have enough incentive to serve these customers, the Federal Reserve System could help the unbanked to obtain access to the financial system. Access to digital currency would not only promote better financing options for the unbanked, but also help them to access the growing e-commerce ecosystem.

4.3.3 To build KYC and AML into the payment system

On November 8th, 2016, the Government of India issued the following notice:

"Government of India vide their Notification no. 2652 dated November 8, 2016 have withdrawn the Legal Tender status of ₹500 and ₹1,000 denominations of banknotes of the Mahatma Gandhi Series issued by the Reserve Bank of India till November 8, 2016.

This is necessitated to tackle counterfeiting Indian banknotes, to effectively nullify black money hoarded in cash and curb funding of terrorism with fake notes.

Starting from November 10, 2016, members of public/corporates, business firms, societies, trusts, etc., holding these notes can tender them at any office of the Reserve Bank or any bank branch and obtain value thereof by credit into their respective bank accounts." [29]

The reason for this notice, as mentioned by the Indian Government, was to deal with black money and hoarded cash. The Government earns money by taxing its citizens. It is, therefore, easy to understand why the government could be motivated by technology, which has the potential to track every penny of interaction between its citizens. If the central bank issues a digital currency and eliminates cash completely, then it could gain direct access to everyone's account information. A complete knowledge of 'who owns what' would allow the central bank to establish complete control over transactions. It would make tax collection much easier.

Know Your Customer (KYC) and Anti Money Laundering (AML) are the two of the largest costs for banks today. They are an ever increasing cause of concern. These costs not only impact the bottom-line of the banks, but also hamper the business as the current systems may filter out the good actors who do not have resources to prove their identity.

However, the central bank controlling and tracking a national digital currency would have immense power to observe and potentially to control an individual's finances. The government could determine how much currency each individual owns and on what and where he spent his money, without the need for any independent judiciary to subpoena the information. Many people prefer to hold hard currency for precisely this reason. If governments issued digital currency, it would create a dangerous temptation for abuse by government.

4.3.4 To enable ubiquitous free payments for all

The Fed facilitates payments between banks, and the increase in digital payments demands a future proof infrastructure that is scalable, fault tolerant, ubiquitous and inexpensive to operate. The payment systems in the United States are now highly fragmented and outdated. U.S. payment offerings are far behind many countries including Brazil, China, Korea, Switzerland and India.

The payment options for B2B transactions in US are limited and antiquated. The change cycles are much longer in the U.S. because the financial system is so vast. In order to address the limitations of current networks such as ACH, and to catch up with the advancements in technology, Federal Reserve has already started a Payment Task Force for Improving the U.S. Payment System. The task force is accessing various technologies for the solution and have underscored the following assessment criteria for the evaluation of payment solution[6]:

- **Ubiquity**: accessibility, usability, predictability, contextual data capability, cross-border functionality and applicability to multiple use cases
- **Efficiency**: enabling competition, capability to enable value-added services, implementation timeline, payment format standards, comprehensiveness, scalability, adaptability, exceptions and investigations process
- **Speed**: rapid clearing, rapid availability of good funds to payee, rapid settlement among depository institutions and regulated non-bank account providers, and prompt visibility of payment status
- **Legal**: legal framework, payment system rules, consumer protections, data privacy and intellectual property
- **Governance**: inclusive governance
- **Safety and security**: risk management, payer authorization, payment finality, settlement approach, handling disputed payments, fraud information sharing, security controls, resiliency, end-user data protection, end-user/ provider authentication and participation requirements

A distributed ledger technology provides advancements in all of the parameters defined by the Payment Task Force.

4.4 Why might commercial banks use distributed ledgers?

Commercial banks provide the actual financial services to the customers, while the central bank provides payment services to banks. Most of the money in the economy is just a number in the bank database, and the databases track the assets and liabilities for everyone.

In the United States, large banks have a history of offering payment systems similar to the ones offered by the central government. CHIPS is an alternative to FedWire, and, therefore, the large value payments are already handled by the existing payment systems. However, there is a clear gap in the solutions for Business – to – Business transactions. Although ACH is inexpensive, the delay in settlement time is not beneficial for businesses. The banks, therefore, would have an incentive to offer a faster payments platform, if they could earn enough profits.

Banks are also the issuers of the credit cards. They bear the credit risk such as default by the credit card user. In the current credit card industry, credit card networks, such as Visa and MasterCard, have a stronger brand then the credit card issuers such as Bank of America. Visa and MasterCard provide services for a hub and spoke network and a distributed Blockchain based network might eliminate the need of a hub and spoke model. This is an opportunity for the credit card issuers to not only build a stronger brand but also to save on their costs.

5 Payment system architectures enabled with distributed ledgers

Based on the identified goals of the central bank, there are two primary ways in which it could use the distributed ledgers. The first option would be to enable direct central bank accounts to everyone. The second alternative would be to improve the current payment infrastructure by using Blockchain. The commercial banks, on the other hand, could rebuild a credit card network or offer new credit cards which do not depend upon the existing credit card networks.

5.1 Direct central bank accounts

Under this approach, the central bank would offer every citizen an account at the Fed. Anyone who has a device with an internet connection would be able to store value in the Fed issued digital currency.

Banks already have an account at the Fed. First, Fed could introduce an accounting system that works on a Blockchain based ledger. The banks would need to integrate with this system, and they would convert all of the transactions between the banks and the Fed to ledger based transactions. Any transaction between the users and merchants could happen through a single interface provided by the Fed. In addition, customers would need a way to check their balance and transactions. Therefore, internet or mobile banking would be a minimum requirement, and telephone banking would be necessary for some account holders.

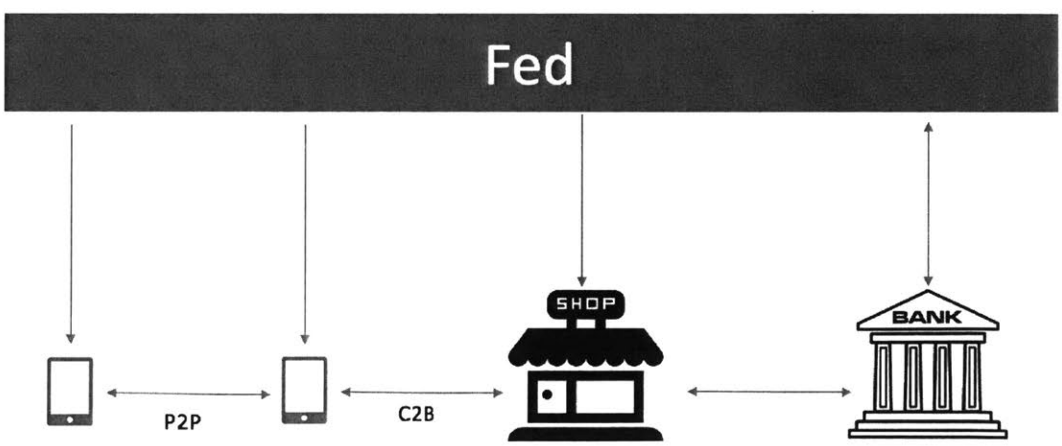

Figure 10: Direct central bank accounts

5.1.1 Technical Design Elements

- **Ledger maintenance and development:** The ledger maintains a record of "who owns what". The central bank already maintains these records for commercial banks. The new ledger would have to allow anyone to maintain a balance in the central bank balance sheet.

- **Issuance:** The Fed prints dollars when a commercial bank demands currency to circulate to its customers. However, in the Bitcoin Blockchain, the miner who confirms the transactions is awarded bitcoins and thus generates money in the ecosystem. The control and distribution of digital currency would have to be determined. Central bank digital accounts could initially be funded by permitting depositors to convert existing currency. The new digital currency would reside on a ledger operated by the central bank.

- **Technical role of entities:** Bitcoin is based on a public Blockchain. Therefore, anybody can start a node in the network and contribute processing power. However, it is possible to have different roles of participating nodes in the network. Their roles would have to be decided between the entities which use the digital currency. Some of the roles might include:
  - **Asset issuer:** Node permissioned to issue assets
  - **Validator:** Node permissioned to confirm the transactions on the network
  - **Auditor:** Node permissioned to view the ledger but not allowed to make any updates

- **Conversion between existing balance and digital currency:** Users would need an option to convert between existing account balances and digital currencies. The central bank would have to allow an interface for commercial banks. The interface could enable the commercial bank to transfer money from the user account to the Fed account, which, in turn, would transfer the money to the user's digital wallet.

- **Fraud Protection:** Existing payment systems have developed machine learning based systems to identify the fraud transactions. Therefore, all user accounts are fraud protected.

The central bank would need to implement fraud prevention and anti-money laundering regulations on all accounts.

5.1.2 Issues and Challenges

Central banks have evolved over centuries and played a crucial role in the last economic crisis. Any issue related to a central bank impacts the economy and needs to be well planned. The prospect of opening an account at the central bank and the use of Blockchain to offer the service raises questions that are worth discussing. Is Blockchain required, if the central bank is the issuing authority and controls the network? What would be the impact of cash and digital currencies co-existing in the market? This section discusses these questions and builds an understanding of the tradeoffs.

5.1.2.1 Blockchain or distributed database?

Who can join the network and how are the transactions confirmed, are the two primary questions that need to be addressed before deciding between Blockchain and distributed databases.

First, if anyone can join the Blockchain network, then it is called public Blockchain. Conversely, if the access is restricted, then it is a private Blockchain. Bitcoin is the largest public Blockchain in world. It allows anyone with an internet connection to join as a node and contribute computing power.

Second, Bitcoin uses game theory and the Proof of Work algorithm to confirm the transactions in Blockchain. Proof of Work requires the participants to solve a complicated problem to confirm the new transactions on the network. However, Blockchain based on bitcoin algorithm is slow because the Proof of Work algorithm acts as a throttle to confirm transactions on the network. The difficulty of the problem is adjusted based on the number of participants in the network. A private Blockchain could increase the speed of transactions by delegating the confirmation requirement to identified nodes.

A Blockchain based distributed ledger could be operated by trusted nodes deployed by the central bank. The nodes would process the issuance of currency and confirmation of payments between users.

However, if the responsibility is delegated to the identified nodes, then it might be possible to use the existing rational databases to design the infrastructure. A payment system or a digital currency could easily be built on existing technology, if only a single entity controls the database. Facebook, Google and many other technology firms now have datasets distributed globally. M-Pesa, a mobile phone currency, has been used in Kenya since 2007. Within two years, it had been used by more than half the population of Kenya. The infrastructure of the currency is hosted and maintained by a single entity, Safaricom, and the currency is now used by over eighty percent of the population.

A Blockchain based architecture would only be justified, if it offers considerable benefits over the distributed database architectures possible with the current technology.

5.1.2.2 Risks of single entity controlling all accounts

The M-Pesa payment system has limits on the maximum amount possible in the wallet. The consumer's money is protected, since the telecom company holds the money in a bank account. Even though a single entity is facilitating transactions between a large percentage of the population, the entity is basically a closed loop system and does not hold all the funds available to the consumers.

However, a central bank that aims to provide digital currency would want to hold all of the citizens' assets in the ledger. A government or federal system that runs the infrastructure would run into credibility problems. Rogoff, K.S says that:

"In theory, a government could itself offer debit accounts that were guaranteed to be private. Unfortunately, that promise would not be worth the paper it was written on, so to speak. Given governments' past behavior, who could take such a promise seriously"[30]

A Blockchain based system would enable the design of a digital currency that replicates the anonymity and censorship-resistance of cash. Therefore, the more cash-like a government digital currency is to be, the stronger are the arguments for implementing a Blockchain solution. On the other hand, if the attributes of low denomination cash are not deemed worth replicating, a potential government-issued electronic currency might be best implemented with a regular database system.

5.1.2.3 Digital Currency co-existence with Cash

The US economy stores value in two main instruments: cash and bank balance, which is a number on a ledger maintained by bank. If the Fed plans to adopt a digital currency, the first question that needs to be addressed is whether the digital currency would co-exist with cash or would it be better to strive for cashless transactions, before issuing a digital currency.

The goal "competing with digital currency" and "providing a banking option to unbanked citizens" could be achieved without completely phasing out cash from the economy. Therefore, the possible payments architecture would be similar for these two goals. However, the co-existence of the two currencies would introduce further challenges:

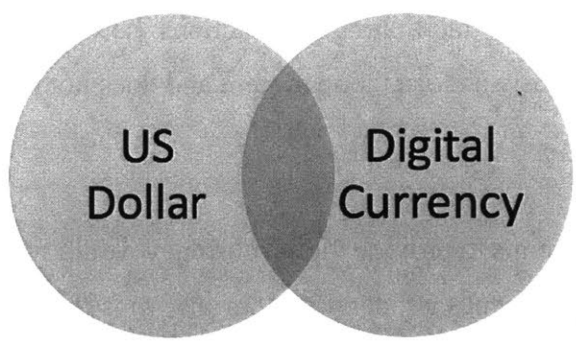

Figure 11: Digital currency co-existence with cash

- **Cross border control:** The U.S. dollar has been a desirable store of value and medium of exchange in times and places where local currency or bank deposits are inferior in one or more respects. It is noted that more than half of the U.S. currency circulates abroad. [31]

The digital currency would be accessible by smartphones and laptops with internet connections. Therefore, it would be much easier than cash to transport outside the United States. A digital dollar would make it easy for anyone around the world to own the dollar. The impact of worldwide dollar availability is outside the context of this thesis, but it needs to be understood.

- **Fungible digital currency:** Cash is a fungible asset. A new twenty-dollar note has exactly the same value as an old twenty-dollar note. However, digital currencies leave a trace on the Blockchain. Newly minted bitcoins are called "clean bitcoins" and are worth slightly more than any other coin on the network. This is because they have no history linking ownership of the coins to any specific wallet address.

5.1.2.4 Would a central bank digital currency cause a death of commercial banks?

It is a misconception that central bank digital currency would lead to drying up of funds for commercial banks, and, therefore, no availability of loans. Banks do not act simply as intermediaries, lending deposits at their disposal. In this view, banks just lend out the money that is deposited by customers. The Bank of England report called "Money Creation in the Modern Economy" defines the process as:

"Commercial [i.e. high-street] banks create money, in the form of bank deposits, by making new loans. When a bank makes a loan, for example to someone taking out a mortgage to buy a house, it does not typically do so by giving them thousands of pounds worth of banknotes. Instead, it credits their bank account with a bank deposit of the size of the mortgage. At that moment, new money is created." [32]

Central banks do not determine the number of loans and deposits in the economy by controlling the supply of central bank money. However, central banks implement monetary policy by setting the price of reserves — that is, interest rates. The "interest rate" established by the central bank drives the bank's decision to lend depending on the lending opportunities available to them.

Therefore, the offering of an extra digital currency should not have an impact on the existing function of the banks. The digital currency would just be a new medium of exchange.

5.2 Revamp payments infrastructure

The Fed provides payment services to banks using a tiered approach. Customers hold funds in bank accounts and the banks hold reserves at the central bank. The following steps occur, when a customer at Bank A wants to transfers funds to a customer at Bank B:

- Bank A reduces the balance for the customer
- Bank A notifies the central bank to transfer the amount from Bank A to Bank B
- Once Bank B receives the payment, it increments the customer account with the same amount.

This approach works, but it is essentially a replication of the manual entry system used to keep accounting. A Blockchain based system allows the connection of multiple entities to the same ledger and to transfer money directly between entities.

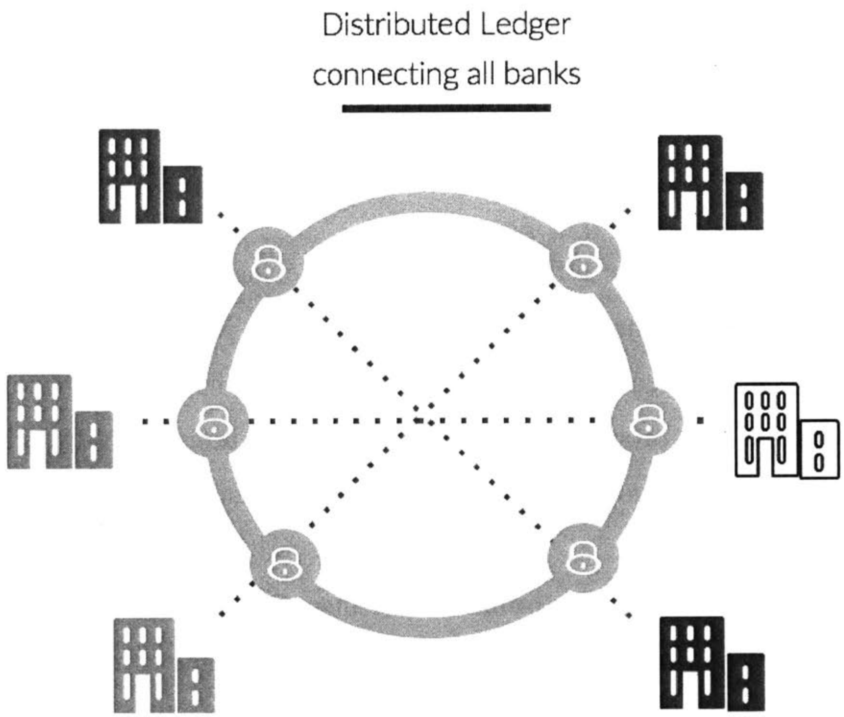

Figure 12: Distributed ledger connecting banks

In the current system, each bank maintains its databases and individually keeps records of the customers. Central bank could offer a Blockchain based platform to connect all commercial banks on a single ledger and thus enable direct transactions between banks.

5.2.1 Technical Design Elements

- **Every bank runs a node for processing transactions:** Instead of central bank running the payments infrastructure, this paradigm calls for a shared ownership for processing transactions. There are two alternatives for implanting this ledger: Bitcoin style Proof of work or Ethereum – proof of stake Blockchain. Since all of the banks would have an incentive to keep running the system correctly, a Blockchain with an Ethereum style consensus algorithm would be efficient in this scenario.

- **Central registry for banks:** Commercial banks would need to know the identifiers of other banks to transfer the value. The central bank provides a registry service that converts the existing sort codes etc. to Blockchain based addresses. The banks use the service to get the public key of the required bank and make the transfer using the Blockchain protocol.

- **One payment system for all bank needs:** Since the current payment systems have evolved based on old technologies, they are error prone. Manual intervention is required at many steps in the process. The Blockchain based payment system could replace the existing systems that process checks, ACH and wire transfers. A single system would reduce complexity for transferring money between counterparties.

- **Cost distribution based on the number of transactions:** In the current payment network, the Fed develops and maintains the payment systems and the commercial banks pay a fee for using the systems. In a Blockchain based infrastructure, all banks would contribute the processing power. As a result, there would be no single point of failure. The banks would have an incentive to participate, since they would earn the native currency by confirming transactions.

5.3 Credit card network with distributed ledgers

In 2016, about two thirds of non-cash payments in the United States were either credit card or debit card transactions[6]. Card use is increasing at about 7 percent per year. The increase in penetration of this payment method can be easily explained by the value that the stakeholders receive.

Card holders not only get the ability to pay without cash, but also gain from the lucrative credit card rewards and bonus programs. Credit card consumers are also covered by 'Fraud Protection programs' and thus do not have to worry about the liability. Credit card issuers and credit card networks run machine learning algorithms to detect fraud before it happens.

Merchants benefit from accepting cards because credit cards provide an easier way for consumers to pay, and anything that improves consumer interaction benefits merchants. By accepting cards, merchants also reduce the effort to collect and deposit cash.

Issuer and acquirer banks also benefit from this arrangement, since they generate more business with their customers. They also earn various card related fees from consumers, and thus increase the bottom line.

Payment Processors such as Vantiv and First Data are also key players in the industry. They interact with the merchants and enable them to accept credit cards as a payment method. Payment processors also develop the software systems to connect and maintain the data requirements of the credit card networks.

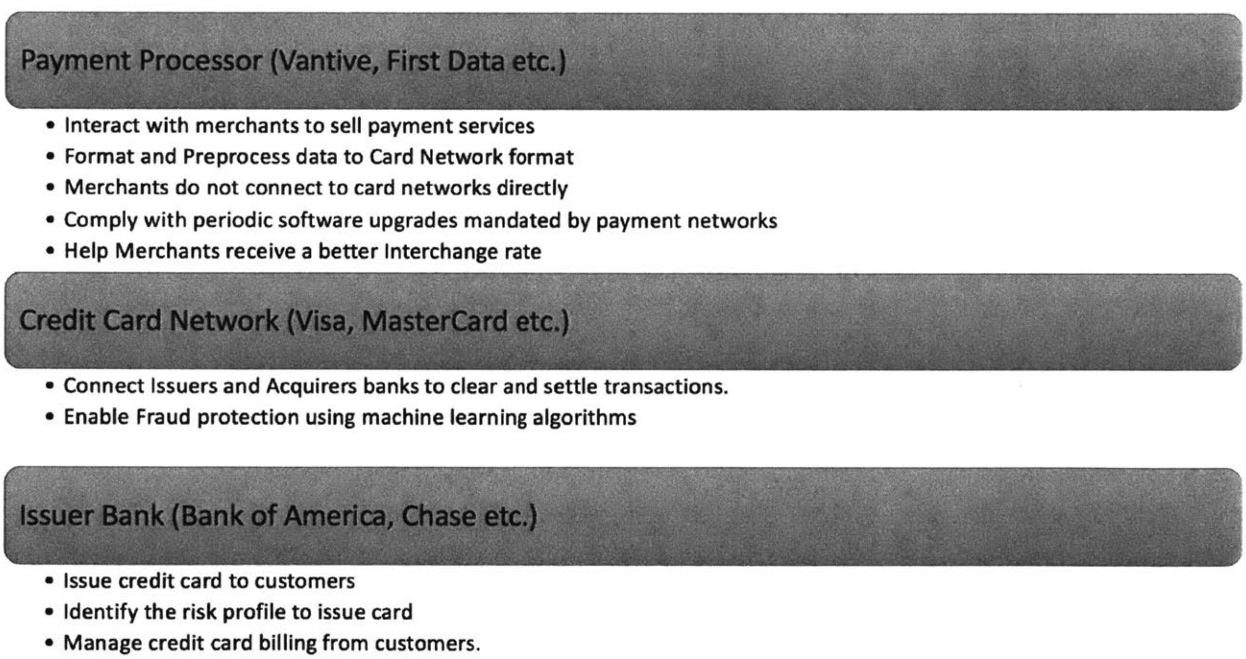

Figure 13: Credit card: role of stakeholders

Decentralize credit card processing

Visa, MasterCard and other credit card networks play two major roles in processing transactions. First, the network providers act as hubs to connect the issuer and acquirer banks. Second, they provide fraud protection services and try to limit the risk for the banks. These credit card networks, in turn, collect fees for providing these services. Credit card networks have also invested in massive machine learning systems to catch fraudulent transactions at the merchant and reduce the risk for the banks.

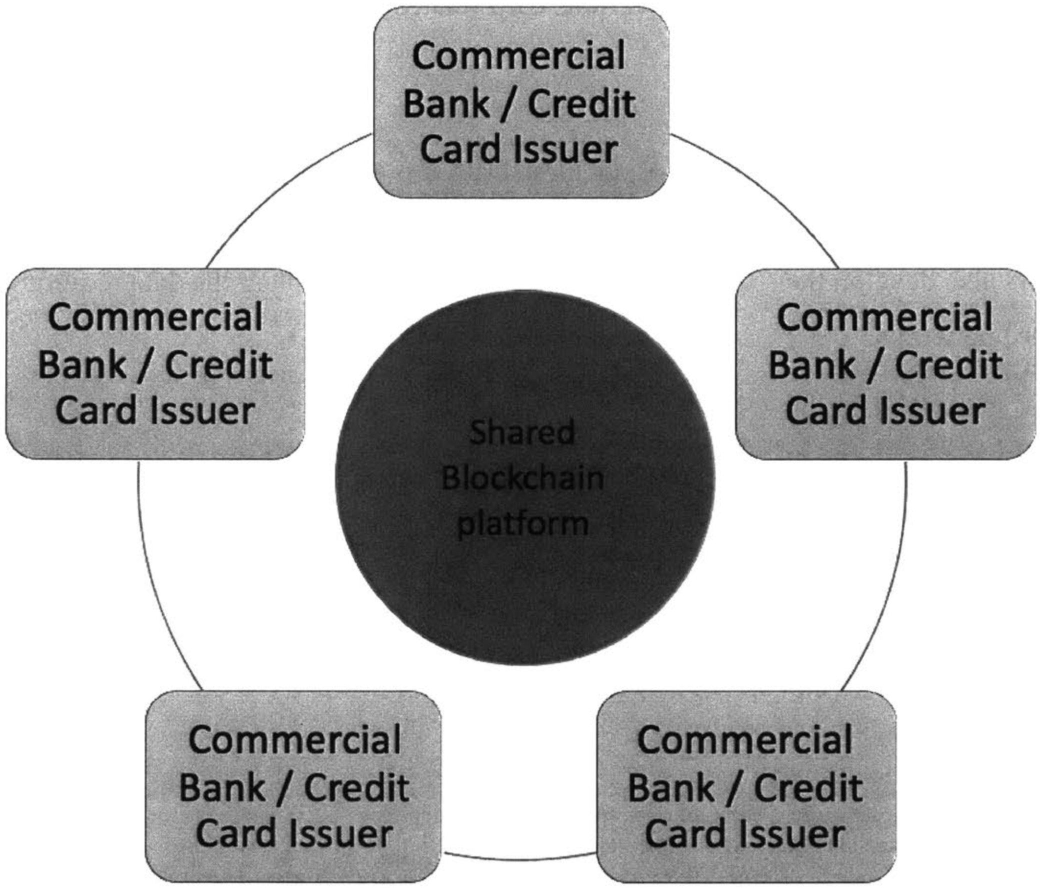

Figure 14: Decentralized credit card processing

A distributed ledger can easily disrupt the intermediary role played by the payment networks. A payment system based on Blockchain, could connect all of the banks on one network and allow them to clear and settle the transactions between them instantly. The network could also allow the acquirer banks to deliver the fees directly to issuer banks. However, since this model would remove an intermediary, the fees could be reduced considerably. In addition, a decentralized Visa network would provide the following benefits to the banks.

- **Network brands more powerful than issuer brands**: Credit card networks such as Visa and MasterCard have a stronger brand than the credit card issuers such as the MIT Federal Credit Union. Although this increases consumer confidence since they are assured that the card by the issuer would be accepted anywhere, the situation is troublesome for banks.

- **Systems operate on batch processes**: Even though the credit card authorization happens in real time when the customer swipes the card, the actual payment process is still processed in batches. Payment processors compile the files from merchants at the end of the day and send to Visa for processing.

- **Cumbersome Receipt handling at merchants**: Merchants have to keep a signed copy of the receipt from the customers. They have the liability of reproducing the receipt in case of disputes from customers.

5.4 Virtual credit cards

The smart phone revolution has enabled new players in the payments business. Apple and Google have entered the payments business by introducing mobile wallets which enable the customers to pay using their mobile phones. Payments using smartphones not only increase the security by using biometrics, but also open new data collection possibilities for the device manufacturers.

The customers can onboard their current credit cards on the new payment wallets and start using their phones for payments. However, when the customer uses the smartphone at the merchant's terminal, the transaction is converted to the existing credit card format and flows through the exiting payment rails. This is an example of an incremental update that does not use the full potential of the available technologies.

The Blockchain technology allows Google, Apple or any of the mobile networks to build a network based on a distributed ledger that allows instant settlement between the banks. They would offer much cheaper services to issuers, since they would be able to benefit more from the customer data and targeted advertisements rather than interchange fees. By using this platform, the credit card issuers could provide 'Virtual Only' credit cards to the consumers. These virtual credit cards would exist on an application of the phone and could offer C2B (consumer to business) and P2P (peer to peer) transactions to the users. Virtual credit cards could also be linked to the authenticated devices of consumers and enable payments directly to online retailers.

6 Conclusion

Payment systems are moving from being a channel for transferring funds to a much wider integrated network for transferring additional forms of value. As the world economy is becoming more digital, the demands on the existing infrastructure are increasing rapidly. A well-functioning scalable foundation is essential to efficiently and safely process advanced payment requirements.

As the payment systems in the United States are lagging behind the developments in many other developed countries, it is crucial for the financial services industry to explore the opportunities that would enhance the payment rails. The architectures proposed in this thesis are achievable and would demand extensive collective effort from the industry.

Interviews

- Angad Singh, MIT Graduate Student, Worked @ Fiserv (Payment systems for banks)
- Craig Ross, Leader in Payments, Apple Pay
- Athanasios Orphanides, MIT Professor, Former Governor of the Central Bank of Cyprus
- Josiah Hernandez, Chief Strategy Officer at Coinsource
- Anders Brownworth, Chief Evangelist, Circle Internet Financial
- Akshay Krishnaiah, Global Product Head, PayPal
- Michael Casey, MIT Media Lab
- Anish Punjabi , Business Associate, Visa
- Jennifer Hongbo Jiang, Head of Trading, JP Morgan Chase
- Alin Tomescu, PhD student @ MIT
- Faisal Khan, Independent Banking and Payments Consultant
- Brian Arnold. Sr. Software Engineer, Vantiv: Credit Card Processing & Payment Services
- Sanchit Arora Banking/Payments Transformation Consultant at Capgemini UK PLC
- Srinivasa Katuri MD & CEO Transaction Analysts (India) Pvt. Ltd
- Tavneet Suri, Maurice J Strong Career Development Associate Professor
- Thomas Peters Humpert, MIT MBA Candidate 2018 - Working on a project with Reserve Bank of Australia
- Ana M. Gomez, Sloan Fellow MBA Candidate 2017 - Working on a project with Reserve Bank of Australia
- Dr Kamal Bhattacharya, CEO iHub (previously inaugural Director of the IBM Lab in Africa, VP IBM Research) – Attended guest lecture on April 11, 2017
- Kenneth Rogoff, Thomas D. Cabot Professor at Harvard University - The Case for Reducing Cash in Advanced Countries and India's Demonetization Lecture at MIT

Bibliography

[1] "PAYMENT SYSTEMS WORLDWIDE, Outcomes of the Global Payment Systems Survey 2010." www.worldbank.org.

[2] D. S. Evans and R. Schmalensee, *Paying with Plastic: The Digital Revolution in Buying and Borrowing*, Second edition edition. Cambridge, Mass: The MIT Press, 2004.

[3] "THE PAYMENT SYSTEM - PAYMENTS, SECURITIES AND DERIVATIVES, AND THE ROLE OF THE EUROSYSTEM. EDITOR TOM KOKKOLA, SEPTEMBER 2010 - paymentsystem201009en.pdf." [Online]. Available: https://www.ecb.europa.eu/pub/pdf/other/paymentsystem201009en.pdf. [Accessed: 02-Apr-2017].

[4] "GPSS-UFA-Note-October2016.pdf." [Online]. Available: http://pubdocs.worldbank.org/en/504871475847684346/GPSS-UFA-Note-October2016.pdf. [Accessed: 02-Apr-2017].

[5] C. C. Benson and S. J. Loftesness, *Payments Systems in the U.S. - Second Edition*, 2 edition. Menlo Park, CA: Glenbrook Partners, 2013.

[6] "The Federal Reserve Payments Study 2016 - 122216-2016-payments-study-summary.pdf." [Online]. Available: https://www.frbservices.org/files/communications/pdf/general/122216-2016-payments-study-summary.pdf. [Accessed: 02-Apr-2017].

[7] M. Jaremski and D. C. Wheelock, "Banker Preferences, Interbank Connections, and the Enduring Structure of the Federal Reserve System."

[8] K. Hassett, "How the Fed Works," *Am. 19328117*, vol. 1, no. 6, pp. 58–63, Oct. 2007.

[9] A. Andriotis and P. Rudegeair, "Bank Overdraft-Fee Revenue Bounces Back; The 2016 fees were the highest since 2009, the year before the Fed implemented a rule stopping banks from automatically charging overdraft fees on some transactions," *The Wall Street Journal Online*, 16-Mar-2017.

[10] "ACH Network: How it Works | NACHA." [Online]. Available: https://www.nacha.org/ach-network. [Accessed: 03-Apr-2017].

[11] "Fedwire Services Product Page." [Online]. Available: https://frbservices.org/fedwire/index.html. [Accessed: 03-Apr-2017].

[12] *Information technologies for the control of money laundering*. Washington, D.C: For sale by the U.S. G.P.O., Supt. of Docs, 1995.

[13] “CHIPS - FEDERAL RESERVE BANK of NEW YORK.” [Online]. Available: https://www.newyorkfed.org/aboutthefed/fedpoint/fed36.html. [Accessed: 03-Apr-2017].

[14] “US Mobile Payments Market, Forecast to 2020.” [Online]. Available: http://www.frost.com/sublib/display-report.do?id=9838-00-9B-00-00. [Accessed: 28-Apr-2017].

[15] R. Ali and J. Barrdear, “Innovations in payment technologies and the emergence of digital currencies.” .

[16] “Why does Kenya lead the world in mobile money?,” *The Economist*. [Online]. Available: http://www.economist.com/blogs/economist-explains/2013/05/economist-explains-18. [Accessed: 28-Apr-2017].

[17] “Faster payments systems gaining speed in the USA: Expanding scope of servic...”

[18] “Home | NACHA Resource Center.” [Online]. Available: https://resourcecenter.nacha.org/. [Accessed: 18-Apr-2017].

[19] Z.-Y. Lee, H.-C. Yu, and P.-J. Ku, “An analysis and comparison of different types of electronic payment systems,” in *Portland International Conference on Management of Engineering and Technology, 2001. PICMET ’01*, 2001, vol. Supplement, pp. 38–45 vol.2.

[20] N. Jayanth, “Payment and Risk,” *DAWN J. Contemp. Res. Manag.*, vol. 3, no. 2, pp. 60–67, Jul. 2016.

[21] “A Stakeholder Perspective on Successful Electronic Payment Systems Diffusion - download.” [Online]. Available: http://citeseerx.ist.psu.edu/viewdoc/download?doi=10.1.1.127.8131&rep=rep1&type=pdf. [Accessed: 02-Apr-2017].

[22] “Nilson Report Details Card Fraud Worldwide.”

[23] S. Ledford, “Rethinking the future of payments,” *J. Paym. Strategy Syst.*, vol. 9, no. 2, pp. 164–171, Summer 2015.

[24] C. Catalini and J. S. Gans, “Some Simple Economics of the Blockchain,” Social Science Research Network, Rochester, NY, SSRN Scholarly Paper ID 2874598, Nov. 2016.

[25] E. Crawley, B. Cameron, and D. Selva, *System Architecture: Strategy and Product Development for Complex Systems*, 1 edition. Boston: Pearson, 2015.

[26] M. Raskin and D. Yermack, "DIGITAL CURRENCIES, DECENTRALIZED LEDGERS, AND THE FUTURE OF CENTRAL BANKING," *NBER Work. Pap. Ser.*

[27] "The Fed - FAQs," *Board of Governors of the Federal Reserve System*. [Online]. Available: https://www.federalreserve.gov/faqs/about_12594.htm. [Accessed: 15-Apr-2017].

[28] "2015 FDIC National Survey of Unbanked and Underbanked Households." [Online]. Available: https://www.fdic.gov/householdsurvey/2015/2015report.pdf. [Accessed: 15-Apr-2017].

[29] "Reserve Bank of India - Press Releases." [Online]. Available: https://rbi.org.in/Scripts/BS_PressReleaseDisplay.aspx?prid=38520. [Accessed: 24-Apr-2017].

[30] K. S. Rogoff, *The Curse of Cash*. Princeton: Princeton University Press, 2016.

[31] R. Judson, "Crisis and Calm: Demand for U.S. Currency at Home and Abroad from the Fall of the Berlin Wall to 2011."

[32] M. McLeay, A. Radia, and R. Thomas, "Money creation in the modern economy."