

Upcoming research challenges in the financial services industry: a technology perspective

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Abstract Several key transformations in the macro environment, coupled with recent advances in technology, have opened up tremendous innovation opportunities in the financial services industry. However, many research challenges need to be addressed for realizing the full potential of innovation in financial services. Examples of such challenges include context-aware analytics over uncertain and imprecise data, design of user-friendly interfaces for improved expressiveness in querying financial service providers, and personalization based on fine-grained user preferences especially in the presence of sparse data. In this paper, we arrive at these research challenges based on an analysis of the macro environment and technology trends, and provide our vision and perspective on the same.

Keywords: Financial services industry · Macro environmental trends · Financial technology · Intelligent digital mesh · Innovations

1 Introduction

Over the past decade, there have been several key transformations across many aspects of the macro environment in which the financial services industry operates. Such aspects include demographics and social behaviour (e.g., prevalence of social media, significant increases in life expectancy, and emergence of the millennial generation), globalization (e.g., effect of natural and man-made disasters on global supply chains, protectionism, war/terrorism, and business process outsourcing), economics (e.g., recession markets, unstable labour markets, and higher unemployment rates), legal (e.g., stricter financial reporting and compliance requirements from Securities Exchange Commissions of different countries, and accounting policy shifts from GAAP to IFRS), and technology (e.g., the ever-increasing popularity of mobile devices/applications, ubiquitous network connectivity, and improved availability of cost-efficient platforms for analyzing big data). Such a transformation in the macro environment, coupled with data about such aspects (which was previously unavailable, especially in real-time), has opened up avenues for creating a major paradigm shift in terms of innovation in financial services as a key value proposition to end-users (both individuals as well as firms).

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The macro environmental factors mentioned above have resulted in a significant amount of activity in the financial products and services space. “Financial technology” (abbreviated as “fintech”) refers to any technology-based innovation in the financial industry [1-2]. Innovations concerning fintech essentially cover the entire gamut of financial services ranging from loan/mortgage management to investment banking to virtual currencies (e.g., Bitcoin [3-4]). Notably, much of this activity is emanating from technology start-up firms that are primarily outside of the traditional financial sector. In order to keep up with the disruptive cross-boundary innovation plays by technology start-ups, traditional financial firms have started pumping funding into fintech companies. To put things into perspective, fintech companies across the world obtained funding to the tune of about \$36 billion in 2016 [5]. For example, Wells Fargo provides mentoring for start-ups, while Bank of America has an annual conference for fintechs in Silicon Valley [6]. Furthermore, BBVA invested \$13.5M on renovating an 80,000 square-foot operation centre in Birmingham for housing technology teams that create fintech applications [6].

In this paper, we review the macro environmental factors and technology trends, and then point out some of the key research challenges that need to be addressed for realizing the full potential of innovation in the financial services industry. We also summarize our perspective on the innovation opportunities that they open up. The remainder of this paper is organized as follows. Section 2 discusses key trends in the financial services industry as well as their ramifications based on an analysis of macro-environmental factors. Section 3 presents recent developments from a technology perspective. Section 4 identifies the key research challenges related to the innovation opportunities in financial services arising out of these factors and trends. It also provides our perspective on how these research challenges, if addressed, could benefit the industry. Finally, Section 5 provides the summary and conclusions.

2 Analysis of macro environmental trends impacting the financial services industry

This section provides an analysis of the macro environment trends in the financial services industry. The trends are summarized in Figure 1 based on the factors of the macro-environment. We now examine how these macro-environmental factors impact the financial services industry.

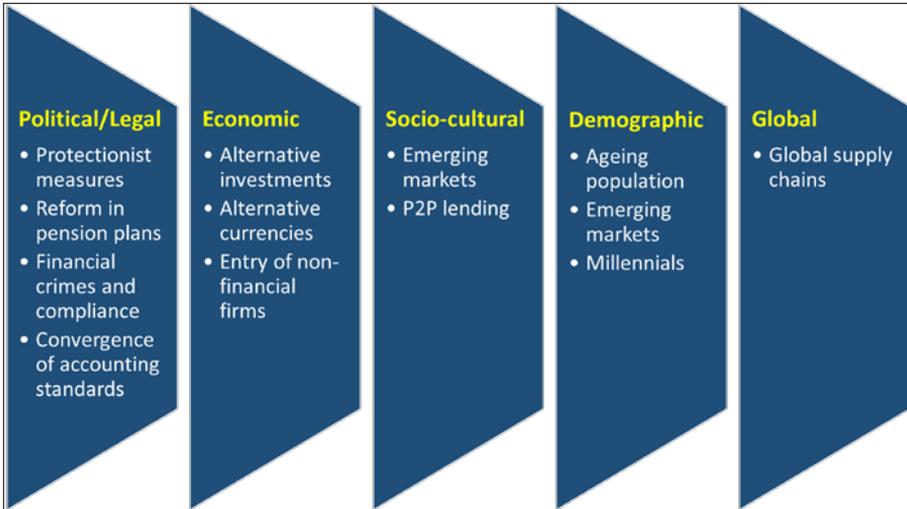


Fig. 1 Macro-environmental analysis of trends in the financial services industry

2.1 Political/legal factors

- Protectionist measures:** In the recent years, governments have been becoming increasingly protectionist in an effort to safeguard the economic sustainability of their respective countries. Examples of protectionist-oriented measures include the creation of more trade barriers, increased import duties, and stricter policies on work visas. A recent example relates to the US administration's H1 visa restrictions [7]. Although some may argue that such protectionist measures may go against the principles of free market economics, the global financial crisis of 2008, the reality of recession markets, as well as the high rates of unemployment have compelled several governments across the world to adopt such measures. The protectionist trend is likely to continue well into the future as well. The implication of protectionism is that product/service differentiation would become a key factor for any given firm to enter the market of a particular country, given that advantages due to offering goods/services at a lower cost would be practically offset by protectionist measures.

Interestingly, protectionist measures open up significant opportunities for research concerning the improvement of financial services and products. For example, consider the case of visa restrictions by any given country. In such a scenario, new tools and technologies can be developed for automated problem-solving and for remote troubleshooting. Furthermore, "intelligent" (see Section 3.1) software could facilitate remote monitoring of the systems for preventative maintenance, in order to reduce the chances of service failures and emergencies.

- Reform in pension plans:** Over the past few years, there has been a trend in terms of a gradual shift from defined benefit pension plans towards defined contribution pension plans [8]. In case of defined benefit plans, employees

typically receive a fixed set of retirement benefits that are not dependent upon market conditions. On the other hand, retirement benefits arising from defined contribution plans depend upon market conditions, thereby creating a significant amount of uncertainty for employees [9]. Given the current economic climate of recession and uncertainty in market conditions, where long-term employment at most firms is fast fading away, we believe that this trend is likely to continue. It is primarily because this trend shifts the financial risk to the employees as opposed to shifting it to the firms. It is to be noted that this shift increases the complexity of long-term investment risk management for retirement asset management firms, especially given that almost the entire portfolio of a given customer entails a high degree of volatility and uncertainty, i.e., no retirement benefits can be taken for granted anymore.

Given such complexity, automation of the analysis of long-term investment risk planning becomes key for effective investment decision-making. Consequently, this trend in pension plans opens up research opportunities towards creating novel financial services that incorporate a considerable amount of automated investment risk planning and decision-making. The challenge here is to design automated financial risk modelling and risk management approaches that are capable of simulating the way in which human financial experts make decisions based on the macro environmental context.

- **Financial crimes and compliance:** Over the last couple of decades, there has been an increase in financial crimes such as financial accounting fraud, securities fraud, credit card fraud, insurance fraud, Internet-based fraud and money laundering. Financial accounting fraud [10-11] perpetrated by companies such as Enron [12], WorldCom [13] and Madoff [14] have shaken public trust in stock markets, thereby resulting in increasingly stringent compliance requirements by regulatory authorities. An example of such compliance regulations is the Sarbanes-Oxley Act (SOX) [12, 15]. Ensuring compliance with respect to such stringent governmental regulations is time-consuming and expensive for firms. It is especially problematic for small to medium-sized businesses. Here, automated fraud detection technologies as well as technologies for creating automated financial reports and statements can play a prominent role in keeping the costs down for all firms. Building such automation technologies raises several interesting research challenges such as heuristics for detecting fraud, intelligent approaches for identifying cases of creative accounting and techniques for working with huge amounts of uncertain data from different modalities and identifying cross-connections and correlations.
- **Convergence of accounting standards:** Over the past decade, there have been several initiatives to combine the two widely used accounting standards, namely the US Generally Accepted Accounting Principles (GAAP) [16] and the International Financial Reporting Standards (IFRS) [17-18]. The goal is to create a unified framework of accounting standards to make the process of financial reporting easier across countries, especially given the importance of globalization [19-22]. Notably, these two accounting standards differ

significantly in terms of their philosophy, thereby creating challenges for accountants. In other words, an accountant, who has been trained in US GAAP accounting standard, would find it challenging to understand financial statements written using the IFRS accounting standard, and vice versa. This opens up new research avenues for the creation of new technologies and software that are capable of automating the process of translating US GAAP-based financial reports and statements to IFRS and vice versa. The challenges here are around interpreting principles expressed in natural language and converting them to algorithms. Furthermore, GAAP and IFRS are philosophically different in that GAAP provides clear-cut quantifiable guidelines for financial accounting, while IFRS is more about principles. The implication is that translation of US GAAP-based financial reports and statements to IFRS (and vice versa) would often be subjective based on the financial experts' human interpretation. Modelling and incorporating such subjectivity into the translation algorithms would open up further opportunities for research.

2.2 Economic factors

- **Impact of alternative investment markets:** Alternative investments refer to investments that are not a part of the standard asset classes (e.g., stocks, bonds and cash). Examples of alternative investments include real estate, futures, derivative contracts and hedge funds [23]. The growth of alternative investment markets [24-25] have been fuelled by investors' increasing lack of trust in the stock markets due to events such as the global financial crisis of 2008 and multiple large-scale scams such as Enron [12], WorldCom [13] and Madoff [14]. Alternative investments can be used for diversifying a given portfolio to reduce risk and volatility, especially because they have little direct correlation with the standard asset classes. For example, Gravitass [26] serves as an outsourcing platform provider for the alternative investment industry. Their thought leadership event in 2015 was aimed at understanding the trends in the alternative investment industry. The areas of focus identified by Gravitass were (a) big data (b) branding (c) cyber security and (d) innovation. While these issues impact the alternative investment industry, they also impact other aspects of financial services, e.g., general (traditional) investment banking services. Hence, addressing these issues would be beneficial to other financial services as well.
- **Emergence of alternative currencies:** The emergence of alternative currencies has been becoming a major trend for the financial services industry. An example of alternative currency is Bitcoin [3-4], which is becoming increasingly popular. While we certainly share the optimism about alternative currencies, we also believe that regulatory frameworks are not yet adequate to deal with alternative currencies. In particular, we believe that the rate of adoption of alternative currencies would depend significantly upon how the regulatory authorities and large financial institutions respond to alternative currencies. This is because the opinions concerning alternative currencies vary across governments. Incorporating alternative currencies into the mainstream

entails research challenges such as traceability, security, trust, privacy, non-repudiation protocols and distributed management of the transactional log data. On the other hand, the rewards for developing technologies that can overcome these problems are huge. As a result, many financial firms, start-ups, as well as traditional IT companies are investing heavily in this area. We will come back to this issue again in Section 3.2.

- **Entry of non-financial firms:** Over the past decade, the financial services industry has been witnessing the entry of firms that are not traditionally financial firms. These firms have been entering the financial services industry with their own expertise and they have been instrumental in continuously redefining the scope of financial services. Examples of new technologies introduced by such firms include Google wallet [27] for payments via mobile devices, Amazon's store card [28-29] for purchase financing purposes and NFC-enabled checkout terminals [30]. Furthermore, companies, such as AT&T and Verizon, are using NFC technologies for creating digital wallets in mobile phones [31]. Moreover, Google has been trying to enter the funds management business, while Apple with its huge cash reserves is also making forays into financial markets.

Additionally, companies, such as Google, Apple and Amazon, have a significant amount of data about their customers. These companies have been increasingly using this data for analytics and bundling their core services with the financial services e.g., for increasingly personalized financial product and service offerings. Given the prevalence of mobile devices and mobile technologies, we believe that mobile services in finance will continue to grow and increase in importance with the key contributions and innovation most likely to come from non-financial firms.

In essence, financial services may no longer remain the sole domain for banks and other traditional financial institutions, as the non-financial firms keep increasing their market share. This would lead to a large-scale integration of financial services with other domains such as retail and travel, thereby bringing in research challenges around the integration and analysis of data from multiple and disparate data sources, including social media.

2.3 Socio-cultural factors

- **Impact of emerging markets:** In emerging markets, two key trends include micro-financing/financial inclusion [32-33], and correspondent banking models [34]. Notably, in emerging markets, a significant percentage of the population are completely excluded from the financial and banking systems and they have little or no access to loans. Micro-financing concerns the small loans that are provided by an organization or private investors to small business owners for enabling financial inclusion and facilitating community development. More recently, the concept of micro-financing has become applicable to start-ups. Consequently, several technological innovations have started to occur in the micro-financing space. As an example, "Kiva" (www.kiva.org) is an online platform that essentially provides a match-making service between private investors and poor entrepreneurs in emerging markets.

Additionally, firms such as Allianz are focusing on innovations in the micro-insurance market.

Over the next decade, we believe that innovations due to technologies such as smartphones and improved credit scoring software (which rely on big data) will create significant positive market disruptions in the micro-financing space. This is also supported by the increasing drive towards entrepreneurship in the startup ecosystems. As more sophisticated data analytics techniques are developed, loan-default analysis would be likely to become more accurate, thereby increasing the trust of investors in the micro-financing space. Furthermore, since micro-financing has the potential to contribute significantly to community development, governments and regulatory agencies have an incentive to provide considerable tax benefits to investors in the micro-financing markets. Here, the role of electronic transactions (e.g., by using mobile devices) would become more prominent because electronic transactions can typically be tracked, thereby alleviating the concerns of governments about money laundering.

Incidentally, the correspondent banking model [34] is becoming increasingly popular towards facilitating financial inclusion for low-income consumers living in remote areas. Correspondents are representatives of a given bank, who are authorized to act on behalf of the bank e.g., in executing various kinds of transactions. Correspondents connect to the banking services requested by the consumers by means of mobile devices. Thus, the correspondent banking model essentially tries to provide consumers with access to banking services without necessitating their physical presence. Given that traditional banks cannot open branches in remote areas due to cost issues, the correspondent banking model has become a necessity to provide financial inclusion to consumers in these remote areas. Furthermore, such areas lack electricity and Internet connectivity, thereby precluding the possibility of installing ATMs.

We see a significant amount of trust issues with Correspondent banking models. For example, a correspondent could be fraudulent and dupe illiterate consumers of their hard-earned savings. We believe that a combination of mobile technologies, security and authentication technologies, as well as stronger government regulations would significantly facilitate in the success of Correspondent banking models over the next decade. Given the recent developments in “intelligent things” (See Section 3.1), it is not unthinkable that some of these issues might find a solution in autonomous vehicles and drones, which could replace correspondents.

- **Popularity of P2P lending:** Peer-to-Peer (P2P) lending [35-36] involves lending money among strangers as opposed to lending from a bank. Based on the study in [37] by Transparency Market Research, the size of the global P2P lending market will be \$897.85 billion by the year 2024, i.e., significantly higher than its market size of \$26.16 billion in 2015. The findings in [37] also revealed that the size of the global P2P lending market is expected to grow at a CAGR of 48.2% between 2016 and 2024. Websites specializing in P2P lending use automated technologies for activities such as credit checking and loan default predictions. In particular, web-based P2P lending firms typically incur considerably lower costs for providing lending services to consumers as

compared to that of traditional banks primarily because of the automated technologies that they use. However, P2P loans are essentially unsecured. In case of any default on a given P2P loan, the lender has no recourse to any legal action.

Interestingly, P2P lending can also be seen as supporting entrepreneurship and innovation in emerging markets (and in some cases, in developed markets as well). In particular, crowd-funding-oriented websites allow potential entrepreneurs to pitch their ideas for novel products and services; then interested individuals can invest money on ideas, which they judge to be of high potential value. We believe that automated technologies for loan default predictions w.r.t. the overall macro-environmental context will play a key role in the near-term as well as long-term future towards further increasing the popularity of P2P lending.

2.4 Demographic factors

- **Impact of ageing population:** Based on the study in [38], the percentage of the world's population over the age of 60 would become almost double in the next 25 years. Ageing of the population has different ramifications for developed and emerging markets. In the case of developed markets, ageing-themed investing has been dramatically increasing in popularity [39]. Examples of ageing-themed investing include investments in healthcare, insurance companies and travel (e.g., cruises). On the other hand, for emerging markets, a huge number of elderly people tend to work with generally unpredictable incomes, thereby implying that reducing risk in their investments and assets becomes a necessity. The financial services industry could play a major role in managing the volatility of individual consumers' investments and assets (e.g., real estate) as well as the volatility of large-sized funds that contain the investments of a large number of firms and consumers. This requires a comprehensive contextual understanding of the environment in which these individual consumers' investments and assets, and large-sized funds operate. It also requires a what-if analysis of different kinds of scenario analysis and reasoning about how the investments would play out under a wide gamut of potential circumstances and events. Hence, in this space, we see significant research opportunities for contextual analysis and fine-grained understanding of financial data.
- **Impact of emerging markets:** In emerging markets such as India and China, the dramatic pace of economic growth has contributed to the middle class expanding at a rapid pace. This trend would imply an increased demand for services towards financing home and car loans as well as investment recommendations for small amounts of money. Notably, such services were originally designed for a relatively small percentage of the population. However, the huge and rapidly expanding size of the middle class in emerging economies, such as India and China, implies that these services need to be provided to a much larger population size than ever before. The ability to provide these services at scale entails some key research challenges related to cost considerations. Here, automated technologies need to be developed to

facilitate economy of scale in providing these services to a large number of consumers. For example, it would be practically unviable to provide individualized/personalized customer relationship managers for everyone in a large population. However, the automated technologies would make it feasible for large population sizes to leverage value from these financial services primarily due to economies of scale. This also requires a significant amount of research in predictive analytics in financial services for understanding the huge amounts of data that are generated from multiple and disparate sources.

There has been a rapid growth in the number of millionaires in Asia. Based on the information in [40], at the end of the year 2015, the net worth of Asian millionaires was \$17.39 trillion as compared to North America's \$16.61 trillion. This market segment of Asian millionaires will increase the demand for personalized advice concerning investments and services associated with the search, sales and financing of high-end products and services. Furthermore, financing of loans for high-end homes would also need to be provided as a service to this market segment. As this market segment becomes larger in size, automation of these financial services would become a necessity to offer the services in a personalized manner. This would create new research challenges and opportunities again with respect to technologies related to digital personal assistants, natural language interfaces, scalability, data collection and analytics, which can be incorporated into "intelligent things" (see Section 3.1).

- **Emergence of the millennials:** According to a Goldman report [41-42], Millennials will inherit \$30 trillion in wealth. This marks a paradigm shift for investment management firms. This is because multiple studies have demonstrated that Millennials tend to rely on information from social networks and the results of their own online research for making financial investment decisions. Notably, this is in contrast with other generations (e.g., Generation X), which typically use the services of financial investment specialists for making their investment decisions. In fact, the survey in [43] indicates that 67% of affluent Millennials would find it acceptable to obtain services from non-financial firms as compared to 45% for affluent Gen X consumers. Furthermore, 91% of affluent Millennials would seek information about financial investments from social networks, while only about 53% of affluent Gen X consumers would be willing to make investments based on information obtained from social networks. Hence, we believe that the emergence of Millennials and their huge \$30 trillion wealth inheritance would lead to innovations in financial investment services. Such innovations would be associated with the collection and analysis of huge amounts of data from social media.

2.5 Global factors

- **Impact of global supply chains:** Trade in supply chains accounted for about \$20 trillion i.e., 60% of the global trade and approximately 30% of the world's GDP in 2013 [44]. Given the significant amount of globalization in today's world, global supply chains are becoming more common and are typically associated with multiple countries across the world [45]. Given that global

supply chains span across geographies, events in any given part of the world can impact the entire global supply chain in an adverse manner. Examples of such events include earthquakes, tsunamis, and regional conflicts. Given that firms typically have marketable securities (investments made by a given firm in other firms) in their respective investment portfolios, the complexity of risk management planning increases dramatically for financial investment firms, especially given the wide gamut of potential exposure due to most major global/local events. This trend again opens up avenues for research in predictive analytics and reasoning under uncertainty for determining the probability and consequences of events that may have considerable impact on global supply chains. Some initial work in this direction may be found in [46-48].

3. Recent Developments in Information Technology

Recent developments in information technology can be summed up in three terms: “intelligent,” “digital,” and “mesh”, i.e., intelligent digital mesh is the way the technology is moving. See for example [49-52].

3.1 Intelligent

- **The trend towards “intelligent things”:** This means that almost any device or artifact that we use in our daily life or professional life could become intelligent, capable of learning and adaptation.

The implication is that artificial intelligence and machine learning would become ubiquitous and will be part of our daily lives. The advent of sophisticated machine architectures and associated learning algorithms, combined with computing power to deal with massive amounts of data as well as the availability of a variety of data (including real-time) from a variety of sources, have the potential to provide huge business value. Access to cheaper and deeper machine learning and advanced chip manufacturing technology (such as the 10-nanometer technology) [50] means that intelligence can be embedded in massive-scale systems as well as in very small end devices. Intelligent apps such as personal assistants that can handle natural language or other immersive interfaces, as well as analytics-enabled features that are integrated into many processes such as ERP, marketing and end-user services will enhance efficiencies of and improve customer experience. “Intelligent things” such as safe robots, drones, autonomous vehicles, and even air taxis [50] are expected to dominate as businesses become more digital. Internet-of-Things (IoT) devices will evolve into “intelligent things” with powerful capabilities.

- **Implications of “intelligent” to financial services:** Financial organizations can be expected to move out of traditional machine learning niche areas such as automated high-frequency trading and venture into broader areas such as fraud and abuse detection, compliance (such as Know Your Customer, or KYC), as well as risk data aggregation and risk modeling. These are some of

the areas that can benefit immensely from the “intelligent” trend. These applications will need to analyze large amounts of diverse data to extract hidden information and to identify complex patterns. The issues related to fraud were eloquently illustrated by the 2016 Wells Fargo account scandal [53]. The idea of “intelligent things” that can send and receive information from the ‘edge’ via a variety of sources such as ATMs, mobile phones, trade centres and financial markets can lead to new types of application scenarios such as real-time risk computation and monitoring. Intelligent assistants are potential game changers that could replace relationship managers and financial advisers. We may also imagine other intelligent things, such as autonomous vehicles and drones, providing banking services in remote areas. However, there are several research as well as regulatory challenges related to privacy and security that will limit some of these applications. We will discuss this again in Section 4.

3.2 Digital

- **The developments towards “digital”:** This means that digital and physical worlds will become increasingly intertwined and eventually seamlessly integrated. Virtual and augmented reality which allows people to simulate and experience situations, will create new business models in the future in terms of providing innovative services. Research challenges in this area are related to freeing up the user from the requirement of wearing appendages such as glasses and capturing the user input (or intent) on a device without a keyboard or a touchscreen (See for example [54]). Digital twins, namely, dynamic software models or physical entities including humans (or organs of humans), will allow us to model real-world situations accurately, leading to a better understanding of the world, including analysis, monitoring and control.
- **Blockchain technology:** Blockchain technology, also known as distributed ledger technology, is also part of “digital”. The technology has its origins in cryptocurrencies (Bitcoin). However, it has now become mainstream, and has the potential to make a substantial impact. The technology works by maintaining identical copies of a digital, distributed transaction ledger in the computers of all participating members. It functions by grouping transactions into blocks and then chaining the blocks. Historical transactions cannot be altered or tampered with, because the links between blocks and their content are protected by cryptography.
- **Implications of “digital” to financial services:** Digital twins will provide financial organizations the capability to understand their customers much better, and thus increase customer satisfaction levels through personalization. Similarly, virtual and augmented technologies have the potential to transform employee training and customer experience. Blockchain technology, which maintains identical copies of transaction history, can bring more trust, better access and transparency to all sorts of value-exchange transactions [55-56].

3.3 Mesh

- **Evolution of the mesh:** The evolution of the digital mesh (which provides dynamic connectivity across people, processes and things), will enable many more applications involving real-time responses. This will be accelerated by technologies such as 5G [57], which will increase the speed of connectivity by an order of magnitude. Conversational systems that use a variety of modalities for interaction (voice, sight, text, touch, gesture) will enable new types of interactions and services. The development of flexible (e.g. fold-up) interfaces will facilitate easy adoption of such technologies. Multi-channel solution architectures that are built on cloud and serverless computing and use APIs and services can be used to deliver dynamic and flexible solutions. Digital technology platforms and services will help build the digital business, streamlining many aspects such as business ecosystems and customer experience.
- **Implications of “mesh” to financial services:** Multi-channel solution architectures, combined with multi-modality interaction, can produce powerful solutions for automating many aspects of financial services such as loan underwriting, reconciliation, risk model development, real-time monitoring, automated portfolio management, and customer relationship management.

4 Research challenges

In this section, we summarize the top research challenges that we believe need to be addressed in order to realize the full potential of the innovation opportunities in the financial services industry. We also point out the typical applications that will be enabled by finding solutions to these challenges:

1. **Blockchain technology:** Blockchain technology is projected to cause the next big transformation in financial services. However, in order to realize its vision, many open problems need to be addressed. Some critical issues are: scalability with respect to performance and latency requirements, extension to scenarios other than cryptocurrency (such as contracts and licensing), and security. If the research challenges mentioned above are addressed, blockchain technology has the potential to reduce the costs of transfer-of-value transactions (particularly across borders), and also fraud. They can also speed up the settlement process in share trading. By pushing identity management to the blockchain, banks can provide a wider range of quick and reliable options to customers for validating identities by eliminating intermediaries. Because blockchains can record anything of value, including contracts, they can also facilitate smarter (intelligent) contracts, where the contracting process as well as the enforcement of the obligations of the contract can be automated. Many banks are already projecting billions of dollars in savings by moving to blockchain technology.

- 2. Analytics and machine learning on big data:** Big data is now ubiquitous and financial services industry is no exception. However, in order to derive the full benefits out of big data, we need to address several problems in advanced analytics and machine learning. These include how to reduce requirements for labelled data (especially in the case of deep learning approaches), how to learn structural as well as complex (e.g. 3D) invariances, and how to perform automated complex reasoning. Deep learning approaches are still plagued by problems such as providing theoretical guarantees, quantifying model complexity, tuning hyper-parameters, and designing architectures to perform multiple tasks. Issues related to analyzing large amounts of financial data include storing personal and private information (e.g., facial images or other biometric data), capture, transferring and storing big data. Other challenges include how to guarantee accuracy or correctness in an automated system. While it is possible to divert specific cases to a human when they are too complex, it is not always possible to identify cases to be sent to human operators automatically. For example, if a machine learning algorithm classifies a certain input with high confidence, we may assume that the algorithm provides the correct answer, but there is no guarantee, due to false positives. Much of financial data is stored in disparate locations in a variety of formats, based on the application and the process in which it is used. This leads to challenges in data storage, transfer, as well as filtering by interestingness or representativeness to reduce computational burden. In the case of analytics, low-complexity, adaptive, sequential, and multi-scale versions of algorithms that are amenable to running on scalable parallel architectures are needed to handle high-velocity streaming data [58-59]. In the case of integration with question answering systems, other analytics problems to be solved are goal-oriented knowledge discovery and context-aware analytics.

Solving the research problems mentioned above will help address many issues in financial services. For example, analytics over huge amounts of disparate data is essential for automatic detection of crime and compliance. Similarly, detection of fraud and identifying cases of creative accounting will involve working with huge amounts of uncertain and imprecise data from different modalities and discovering cross-connections and correlations. Also, as mentioned in Section 2.2, entry of firms from non-financial domains (such as retail and travel) into the financial domain brings in a variety of challenges around integration and analysis of data from multiple and disparate data sources, including social media. Big data analytics can also facilitate remote monitoring and preventative maintenance of systems, thus reducing the cost of services. This is particularly useful in the era of protectionism. Big data analytics and machine learning provide tools for understanding trends in alternative investment markets, and can potentially help design services that provide automated financial investment advice to specific demographic groups such as the Millennials.

- 3. Cyber security and privacy:** Security and privacy issues continue to be of paramount importance in financial applications that run in an intelligent digital mesh environment. In spite of a large amount of effort put into addressing many problems in this area, several challenges remain. Security is not just

limited to storage and transmission of data. Solutions need to integrate security features at every stage. Layered security architectures that use entity behaviour analytics will need to be designed and developed to monitor suspicious activities. Also, owing to many regulatory challenges, much more progress in privacy-preserving analytics will be needed if we were to automate services such as financial advice. Solving problems related to security will also help in problems related to emerging markets. For example, a combination of mobile technologies, security and authentication technologies, as well as stronger government regulations would significantly facilitate the success of the correspondent banking models.

- 4. Intelligent things:** Intelligent assistants are potential game changers that could replace relationship managers and financial advisers. One of the challenges in this area is to combine natural language understanding and conversational technologies to design effective dialog systems that are able to query databases or initiate query-specific analytics (e.g. goal-oriented knowledge discovery and context-aware analysis) that could help synthesize the answer for a user query. In many cases, the answer could also be in the form of a plot or a graph. Other difficult problem to solve is how to generate recommendations on the fly that make sense given the time, geography and other contextual information about the user. Other intelligent things such as self-driving vehicles and drones could have potential applications in delivering services that need physical contact. This could be particularly useful in branchless banking and in reaching out to remote customers in emerging markets. We believe that a combination of mobile technologies, security and authentication technologies, as well as stronger government regulations would significantly facilitate in the success of correspondent banking models over the next decade.
- 5. Natural language understanding and conversational interfaces:** Natural language understanding has made a lot of progress, and has been deployed in scenarios such as question answering in restricted domains. Much of current work is based on statistical methods that requires large amounts of data. On the other hand, many applications in financial services, such as translation of US GAAP-based financial reports and statements to IFRS (and vice versa) will require much deeper understanding of the text (including many nuances) and in the context in which the text needs to be interpreted. The context may include information about the entity about which the report is written, as well as other rules, policies and laws that may apply. The translation process is often subjective and is based on the expert's interpretation. Natural language understanding algorithms that incorporating domain knowledge, context, and other information into would open up further applications in the financial domain. Challenges in conversational technologies include paraphrase detection, deducing the context from the earlier conversations, and discovering user intent.
- 6. Modeling and reasoning in the context of complex dependencies:** Many problems in the financial services industry involve analyzing highly intricate relationships between various financial parameters, market variables, events,

and entities. Changes in the macro environment ripple through the network of such complex relationships, and if not properly modelled and analyzed, can manifest themselves in unexpected ways. Examples of such problems are automated investment risk planning and decision-making in the context of managing pension plans (see Section 2.1), managing individual consumers' investments in the context of the ageing population, and assessing impact of events on global supply chains. All of these problems require comprehensive models that are based on contextual understanding of the environment. The models should be capable of performing predictions and reasoning under uncertainty, because, very often, the information about changes in the macro environment is not precise and reliable.

- 7. Personalization technologies:** Personalization based on fine-grained user preferences, especially in the presence of sparse data, is still a technical challenge. High levels of personalization will need fine-grained segmentation of the customer base. Other dimensions such as personas and geography will further complicate the issue. We also need to create customized content for each segment. Effective matching of the content to the user without storing (or caching) multiple copies of the content will bring in issues related to scalability. Identifying the segment to which a new (or anonymous) user may belong is also a non-trivial problem. Ideally, a “digital twin” needs to be created to understand and model a customer, so that appropriate recommendations can be made in at the right place, right time, and the right context. However, given the restrictions imposed by privacy laws, there are limits to what kind of data may be collected to build such twins. Solving the personalization problem is crucial for several applications such as intelligent agents for personalized financial advice.
- 8. Automated technologies for loan default predictions:** Estimating reliable creditworthiness scores and predicting loan delinquency or default based on peer-to-peer interactions, transaction history, other online behavior (including social media data, when available), and limited demographic data is still a largely unsolved problem. The solution to this problem will play a key role in the near-term as well as the long-term future towards making P2P lending more attractive to investors and participants.
- 9. Virtual and augmented reality technologies for customer interactions, training and remote support:** In many situations, physical presence of an agent or an employee of a financial organization to address a customer problem may not be feasible. This can be due to protectionist measures, cost of travel, availability of personnel, cost of training agents, etc. The challenge is to develop technologies based on virtual/augmented reality and intelligent agents to handle such situations. For example, new tools based on these technologies can be developed for providing self-help to customers for problem-solving and trouble shooting. Similarly, “virtual banks” can provide a scalable solution to the problem of branchless banking. Design of user-friendly interfaces (other than key pads) for collecting user input is critical for the success of solutions based on virtual and augmented reality.

5 Conclusion

We are living in exciting times of dramatically fast-paced innovation in the financial services industry in the form of novel financial products and services. Given this background, we have reviewed the macro-environmental factors and technology trends that are giving rise to this innovation, and identified some of the key research (technical) challenges that need to be overcome if we want to realize the full potential of the innovation opportunities. We envisage a future in which such financial products and services would be offered increasingly by a wide gamut of stakeholders (including start-ups) outside of the traditional financial institutions to meet the high expectations and preferences of newer market segments that are emerging, (e.g., the Millennials and the ageing population). The day may not be far when a person in a remote location might “walk into” a virtual bank to order a credit card that may be delivered by a drone, or a personal assistant might help manage the investments of a Millennial.

We believe that the solutions developed in response to the research challenges faced by the financial services industry would also be broadly applicable (albeit possibly with some modifications) to other industry domains such as retail, travel & tourism, healthcare, and transportation. As a single instance, the research advances in natural language processing and contextualization of textual data may very well be applied to facilitate users in determining appropriate healthcare vendors that are aligned with their preferences or to automate insurance claims. We hope that researchers from academia, industry and other government organizations will come together to realize these innovations in the financial services space.

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