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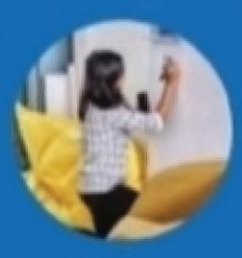
IBM Leadership

#1 AI for business
20,000+ IBM Watson client engagements across 20 industries.

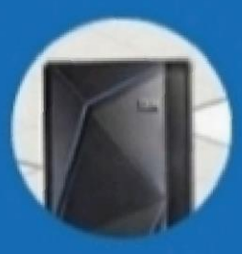
#1 in hybrid cloud
47 of the Fortune 50 rely on IBM Cloud. Revenue for IBM Cloud topped $19 billion in 2018.

#1 in enterprise services
IBM Services, with end-to-end cloud and AI capabilities, closed 47 client agreements worth more than $100 million each in 2018.



#1 in enterprise security
IBM Security manages 70 billion cybersecurity events per day for clients in more than 130 countries.

#1 in enterprise systems
IBM Z is at the heart of world commerce with 30 billion transactions per day, including 87 percent of all credit card transactions.



#1 in blockchain
IBM Blockchain Platform was ranked number one by analyst firms Juniper Research and Everest Group.

#1 in U.S. patents for the 26th consecutive year
IBM inventors received a record 9,100 patents, including more than 3,000 in AI, cloud and quantum computing.

#1 and #2 fastest supercomputers in the world
Built by IBM for the U.S. Department of Energy, based on IBM POWER9 CPUs tuned for AI workloads.

That is why businesses moving to Chapter 2 will need to embrace a new, hybrid cloud approach. It is one that will allow them to more easily move data and scale AI and other applications across public, private and on-premise IT in their enterprises, with consistent management and security protocols, using open source technology.

For example, BNP Paribas, a leading European bank, is working with IBM to speed and scale the launch of new digital and AI customer services across the cloud, while protecting the security and confidentiality of customer data. Similarly, global telecom leader Vodafone Business is partnering with IBM to innovate the way it delivers multicloud and digital capabilities—including AI, edge computing, 5G and software-defined networking solutions—to its customers.

IBM Services provides end-to-end cloud integration capabilities and is helping thousands of businesses migrate, integrate and manage applications and workloads seamlessly and securely across any cloud environment. Industry experts from IBM Services are co-creating cloud-enabled solutions with clients in our IBM Garages. Using design thinking and agile methods, we are helping clients implement new ways of working, such as rapid prototyping and iteration to more quickly move technology projects from pilot to production at scale.

> "We are ready for this moment of moving clients to Chapter 2 of their digital reinventions with our unique integration of innovative technology, industry expertise and a reputation for trust and security earned over decades."

We are ready for this moment of moving clients to Chapter 2 of their digital reinventions with our unique integration of innovative technology, industry expertise and a reputation for trust and security earned over decades. IBM is now moving the world's major enterprises to the next era, an effort that will be enhanced by our planned acquisition of Red Hat.

Chapter 2 of Trust and Responsible Stewardship

We recognize that our clients and the consumers they serve expect more than groundbreaking innovation and industry expertise. They want to work with technology partners they can trust to protect their data and handle it responsibly. They want to work with partners who know how to bring new technologies into the world safely and help society benefit from them. And they want their partners to create inclusive workplaces and communities where diversity thrives.

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QUANTUM UNDERSTANDING

ExxonMobil's vice president for Research and Development, Vijay Swarup, is leading the company's exploration of quantum computing.

Every energy company's dual challenge:

Provide access to scalable, affordable energy

Reduce the risks of climate change

Vijay Swarup, ExxonMobil vice president for Research and Development, says energy research requires curiosity, optimism, patience and dissatisfaction. Dissatisfaction because he believes things can be better. But what, exactly, can be better? Nothing less than our understanding of the world.

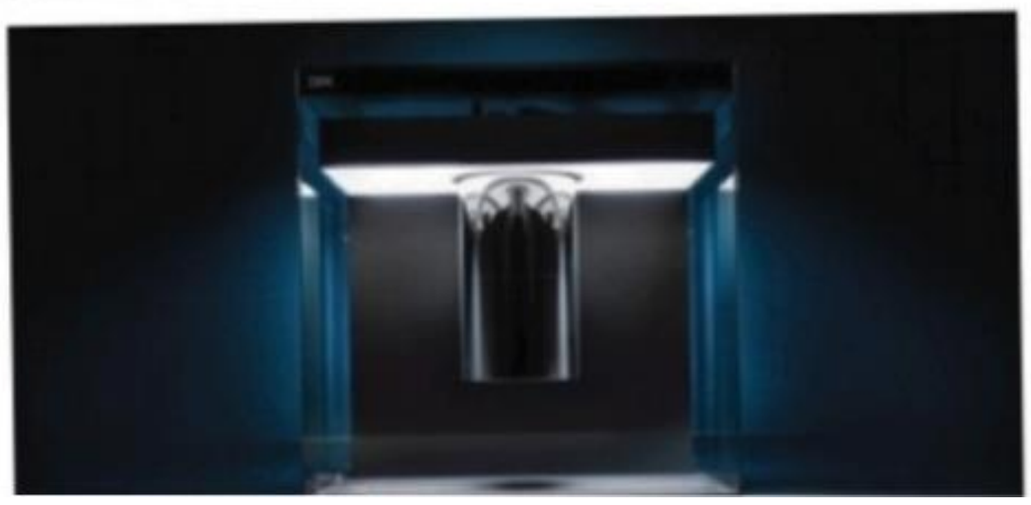
Researchers now have a new tool to explore new ways to solve problems: quantum computing. And Vijay's quite precise about the trouble with our current understanding. "There are some problems so big, all we can do is approximate," he says. Whether he's in a business suit or the lab coat he wears at ExxonMobil's expansive New Jersey research facility, Vijay clearly enjoys trying to solve what he calls today's pressing dual challenge: ensuring that people have access to scalable, affordable energy, and doing so in the context of climate change and the need for sustainable solutions. This is where IBM Q comes into the picture. Quantum computers have long been considered theoretical. But today, they're becoming a reality, with huge potential for energy companies like ExxonMobil. That said, using a quantum computer also calls for significant change in how researchers think about approaching their work. "Computation has always been an integral part of the research we've done here, but quantum's radically different," Vijay explains. "Now, we must first figure out which problems are most suited to a quantum approach and only then can we answer a more interesting question: How can you program a quantum computer to solve energy problems?"

ExxonMobil joins a group of global corporations partnering with IBM to work side-by-side on IBM's fully functional quantum computers. As Vijay says, quantum's a priority that requires pairing the "best minds with the best minds." So ExxonMobil has a team that will meet regularly with IBM's quantum researchers. Barclays has its own team working on quantum, as do Samsung and Daimler. Working as part of the IBM Q Network alongside global universities and national research labs, these corporations see the potential of a massive shift in how computers can help solve some of the most enduring challenges—issues that, once solved, could transform entire industries.

"IBM Q System One is the world's first integrated universal quantum computing system designed for scientific and commercial use," says Dario Gil, director, IBM Research. "We are at the beginning of an exciting journey. Our research, systems and business teams—along with our IBM Q Network partners—have a bold vision. They are thinking big. These are the true pioneers."

Nature is no longer estimated but predicted and understood. That's the goal. So when IBM unveiled its quantum machines, companies like ExxonMobil saw great promise. But when you talk to Vijay about promise, his thoughts turn to the great needs that are facing the world. "Our global population is increasing from 7 billion to 9 billion and, all across the world, a growing middle class requires more resources and, especially, more energy." Quantum might be well suited to solve super-complex problems, such as advanced models which could lead to better approaches to carbon capture and lower emissions sources of energy. But what excites Vijay most is that the collaboration with IBM researchers could lead to a fresh ability to predict and anticipate how nature operates—which could lead to an understanding of what's *actually* happening, as opposed to an approximation of what *might* be happening. "With a little curiosity, patience and not settling for the status quo, I know we can get there," he says.

IBM Q System One is the world's first integrated quantum computing system for commercial use.



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More clients are partnering with IBM to write the next chapters of their digital reinventions.

Maersk, the container logistics giant, is using **IBM Blockchain** to create TradeLens, a global blockchain solution for the shipping ecosystem. This global transformation will lead to faster delivery times, lower costs and a noticeable difference in the way we get the things we use every day.

KMD, Denmark's largest technology company, is dedicated to connecting its clients to the latest technologies. The company is using **IBM Services** to provide a critical foundation of servers, networks and other technologies that help it handle large volumes of data with high levels of security.

Whirlpool Corporation is using **IBM Cloud** to help manage all the data from its manufacturing of connected home appliances. Whirlpool will be using the cloud to manage critical enterprise applications, which will give it more flexibility to scale and innovate.

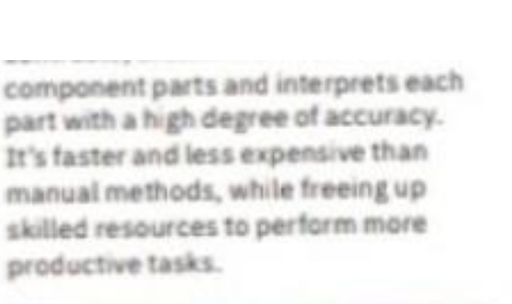
Telefónica turned to **IBM Blockchain** to capture call data in real time and save it in a format that's trusted, traceable and accessible to network providers and carriers worldwide, making international phone calls feel seamless despite all the technological leaps they require.

Smart Dubai, working with **IBM Blockchain** and **IBM Cloud**, has launched the region's first government-endorsed blockchain service: Dubai Blockchain Platform. It is designed to make the technology more accessible to the Dubai government, the UAE national government and private companies.

Suunto, creator of the Movesense microsensor, launched a Movesense development community enabled in the **IBM Cloud**. This let Suunto dramatically scale its offerings. Today, more than 800 developers are working with Movesense, helping Suunto bring the device to new customers all over the world.

component parts and interprets each part with a high degree of accuracy. It's faster and less expensive than manual methods, while freeing up skilled resources to perform more productive tasks.

Krungsri Bank, one of Thailand's largest financial institutions, is working with **IBM Services** to lay the foundation for its future. An **IBM Blockchain** pilot is in progress, and the bank is planning to develop new services for its customers.



Profility, a post-surgery rehabilitation solutions provider, needed to integrate large volumes of data as well as meet stringent HIPAA regulations. They chose **IBM Cloud** because of its flexible software and secure, dedicated hardware. Their system is widely used and has resulted in shorter rehab stays and fewer hospital readmissions.

The Australian Federal Government has set its sights on being one of the world's top three digital governments by 2025. In July 2018, it announced a five-year agreement that covers solutions from **IBM Cloud**, **IBM Watson**, **IBM Security**, **IBM Research** and the **IBM Q** quantum computing initiative.

Beiron applied **IBM Watson** Visual Recognition to its Autoglass Body Repair business to speed up insurance processing, move repairs along quickly and help its customers get back on the road fast.

Thought Machine, a London-based fintech startup, has built Vault, a new, cloud-native core banking infrastructure launching on **IBM Cloud**. It has also partnered with **IBM Services** to provide advisory and delivery capabilities to its clients.

Travelport, a travel commerce platform, is working with **IBM Watson** to integrate disparate information sources and make stronger corporate travel recommendations. As a result, finding the lowest travel costs for a company will be quicker and easier.

Japan Airlines is using an **IBM Watson**-powered chatbot, Makana-chan, to answer customers' questions about its popular Tokyo-to-Honolulu flights. Makana-chan eases the burden on live agents and is very popular with passengers.

Bausch + Lomb simplified the service and maintenance process for its high-tech Stellaris Elite Vision Enhancement System for cataract and retina surgery. Using **IBM Cloud**, the company can now pinpoint or respond to technical and service requests and limit or minimize downtime.

Fluor Corporation builds mega-projects across the globe. Data generated by these projects has been harnessed by working with **IBM Research** and **IBM Services**. Fluor recently introduced two new AI-powered systems to uncover and predict how unmitigated trends could affect key project indicators.

BNP Paribas is accelerating its digital transformation and improving its operational efficiency. The bank will now integrate **IBM Cloud**-hosted data centers dedicated to the bank, and will strengthen its hybrid cloud "as a service" capabilities while ensuring the security and confidentiality of their customers' data—including not using public clouds for hosting any customer or other production environments with sensitive information.

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Responsible stewardship and trust have been hallmarks of IBM's culture—from our labs to the boardroom—for more than a century.

IBM is recognized as one of the World's Most Ethical Companies by the Ethisphere Institute, highlighting our influence in driving positive change in business and society around the world.

Data Responsibility

At IBM, we've always followed straightforward principles to act responsibly and earn trust. Today, our principles include:

- The purpose of new technologies is to augment—not replace—human intelligence.
- Data and insights belong to their owner.
- New technology, including AI, must be transparent and explainable.

Recent actions demonstrate our principles at work, including:

- **Advocating for public policies to protect the privacy and security of data** and working with governments worldwide on strategies that will ensure privacy and responsible handling of data, without undermining innovation.

- **Partnering with STOP THE TRAFFIK**, law enforcement and financial services institutions to stop human trafficking by using IBM software analytics to identify suspicious trends, hotspots and financial transactions.

Modern slavery, a $150 billion business, has a new foe: an AI data hub on the IBM Cloud.

- **Launching AI Fairness 360**, an open source software toolkit to help developers actively detect and reduce bias in datasets and AI.

- **Releasing Diversity in Faces, a first-of-its-kind dataset,** to help reduce bias in facial recognition systems, making them fairer and more accurate.

1 million annotated human facial images

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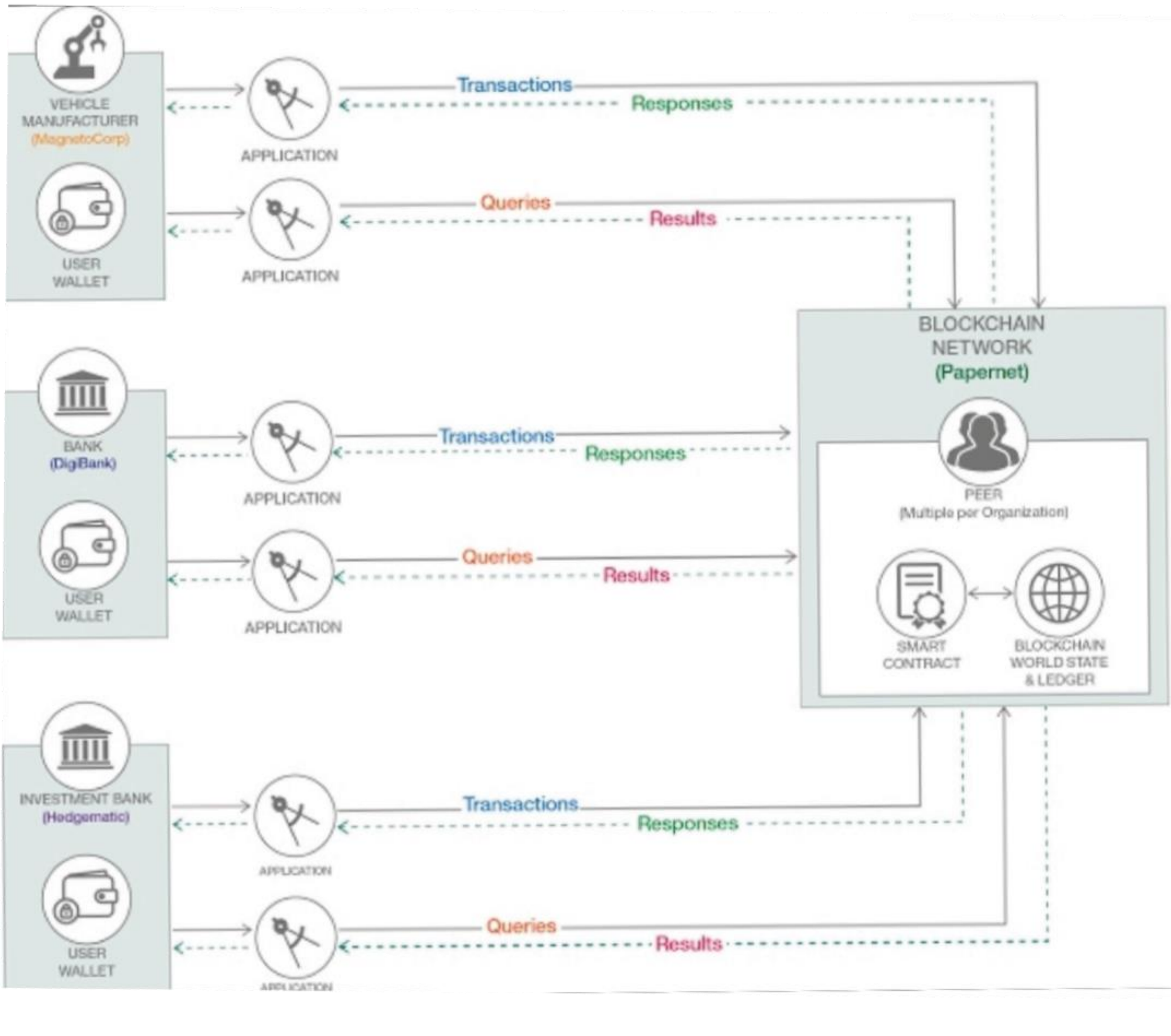

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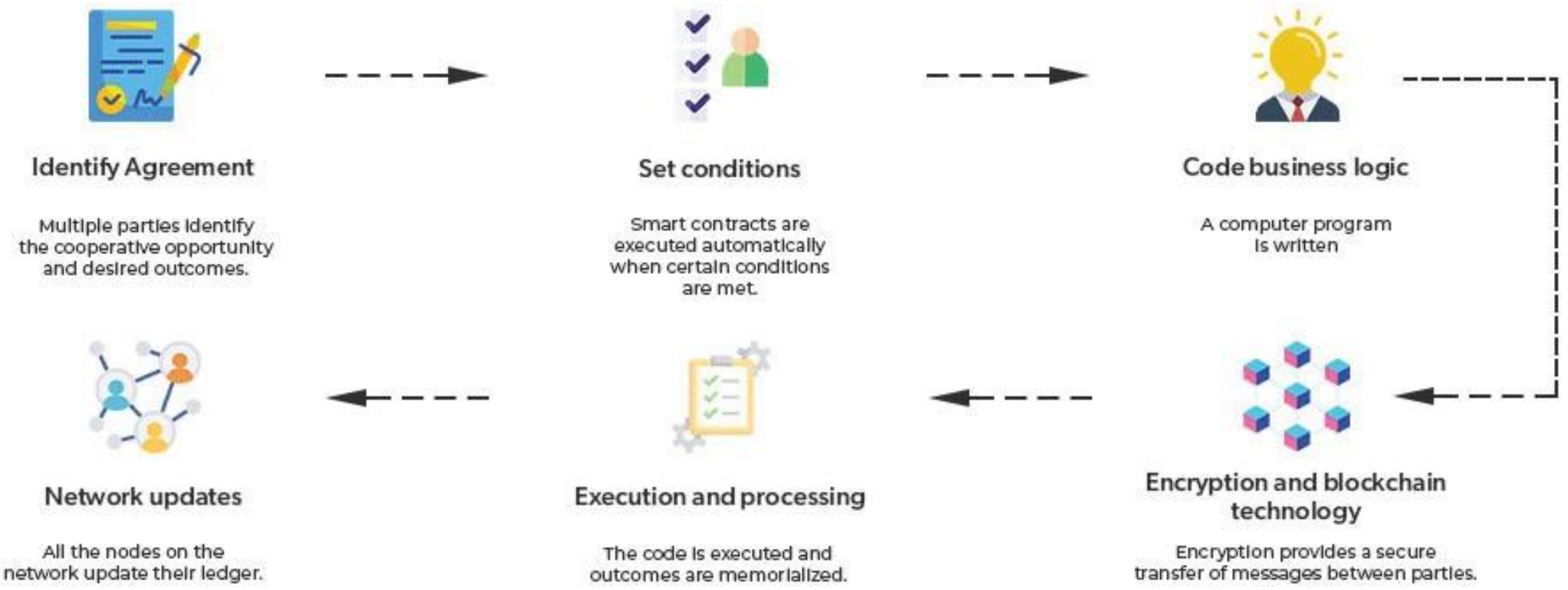
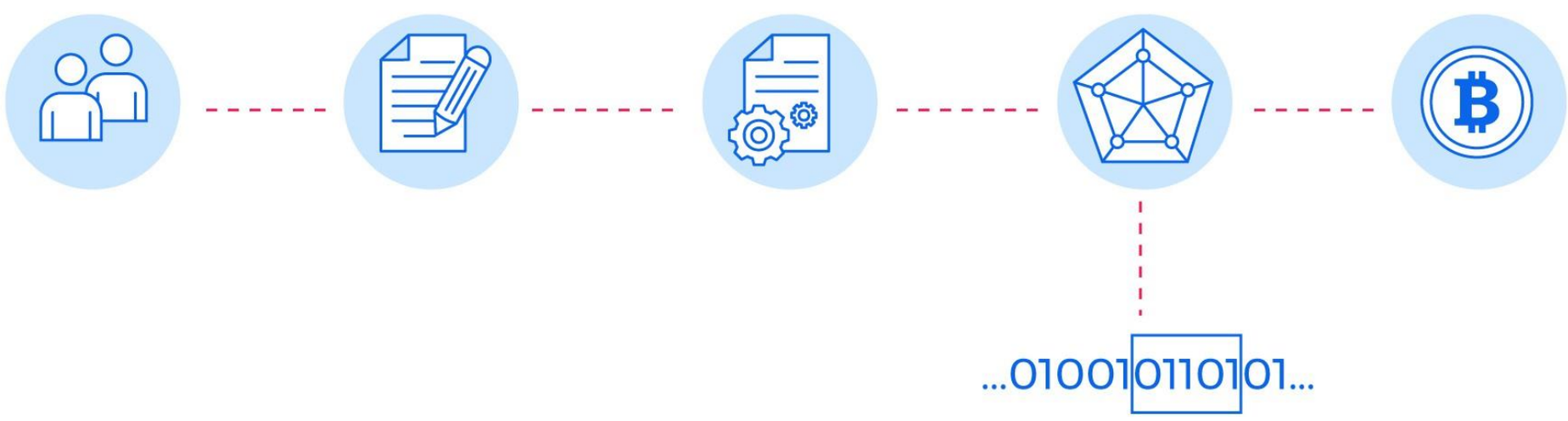
EPCOR UTILITIES IBM-SMART_CONTRACT

How does a
Smart Contract Work?



SMART CONTRACT



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***Abstract*—Smart contract technology is reshaping conventional industry and business processes. Being embedded in blockchains, smart contracts enable the contractual terms of an agreement to be enforced automatically without the intervention of a trusted third party. As a result, smart contracts can cut down administration and save services costs, improve the efficiency of business processes and reduce the risks. Although smart contracts are promising to drive the new wave of innovation in business processes, there are a number of challenges to be tackled. This paper presents a survey on smart contracts. We first introduce blockchains and smart contracts. We then present the challenges in smart contracts as well as recent technical advances. We also compare typical smart contract platforms and give a categorization of smart contract applications along with some representative examples.**

***Index Terms*—Smart contract; Blockchain; Cryptocurrency; Decentralization**

I. Introduction

Blockchain technology has recently fueled extensive interests from both academia and industry. A blockchain is a distributed software system allowing transactions to be processed without the necessity of a trusted third party. As a result, business activities can be completed in an inexpensive and quick manner. Moreover, the immutability of blockchains also assures the distributed trust since it is nearly impossible to tamper any transactions stored in blockchains and all the historical transactions are auditable and traceable.

Blockchain technology is enabling *smart contracts* that were first proposed in 1990s by Nick Szabo [1]. In a smart contract, contract clauses written in computer programs will be automatically executed when predefined conditions are met. Smart contracts consisting of transactions are essentially stored, replicated and updated in distributed blockchains. In contrast, conventional contracts need to be completed by a trusted third party in a centralized manner consequently resulting in long execution time and extra cost. The integration of blockchain technology with smart contracts will make the dream of a "*peer-to-peer market*" come true.

Take a smart contract between a buyer and a supplier as an example. As shown in Figure 1, a supplier first sends a product catalog to a buyer through the blockchain network. This catalog that includes product descriptions (such as property, quantity, price and availability) along with shipping and payment terms is stored and distributed in the blockchain so that a buyer can obtain the product information and verify the authenticity and reputation of the supplier at the same time. The buyer then submits the order with the specified quantity and payment date via the blockchain. This whole procedure forms a purchase contract (*i.e.*, *Contract 1*) enclosed in the blue box as shown in Figure 1. It is worth mentioning that

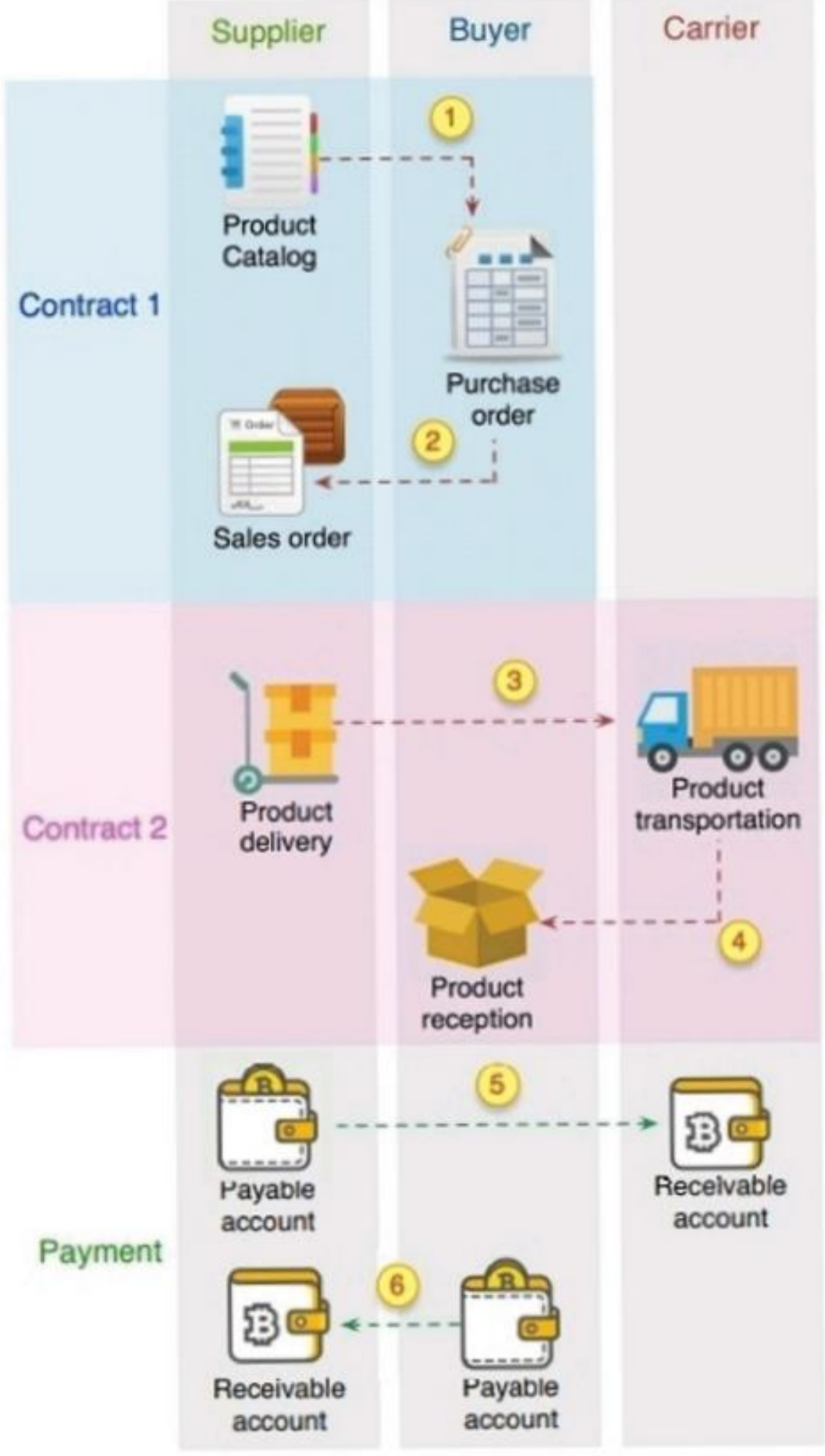

Figure 1. An example of a smart contract between a buyer and a supplier.

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the whole procedure is completed between the buyer and the supplier without the intervention of a third party.

After *Contract 1* is done, the supplier will search for a carrier in the blockchain to complete the shipping phase. Like *Contract 1*, the carrier also publishes the shipping description (such as transportation fees, source, destination, capacity and shipping time) as well as shipping conditions and terms in the blockchain. If the supplier accepts the contract issued by the carrier, the products will be delivered to the carrier who will finally dispatch the products to the buyer. This whole procedure constructs *Contract 2* (enclosed in the pink box) as shown in Figure 1 . Similarly, the whole procedure of *Contract 2* is also conducted without the intervention of a third party.

In addition to automatic execution of *Contract 1* and *Contract 2*, the payment procedures (including the payment from the supplier to the carrier and that from the buyer to the supplier) are also completed automatically. For example, once the buyer confirms the reception of the products, the payment between the buyer and the supplier will be automatically triggered as the predefined condition is met. The financial settlement from the buyer to the supplier is conducted via crypto currencies (*e.g.*, Bitcoin or Ether[1].). In contrast to conventional transactions, the whole process is done in a peer-to-peer manner without the intervention of third parties like banks. As a result, the turnaround time and transactional cost can be greatly saved.

In summary, smart contracts have the following advantages compared with conventional contracts:

- *Reducing risks.* Due to the immutability of blockchains, smart contracts cannot be arbitrarily altered once they are issued. Moreover, all the transactions that are stored and duplicated throughout the whole distributed blockchain system are traceable and auditable. As a result, malicious behaviors like financial frauds can be greatly mitigated.
- *Cutting down administration and service costs.* Blockchains assure the trust of the whole system by distributed consensus mechanisms without going through a central broker or a mediator. Smart contracts stored in blockchains can be automatically triggered in a decentralized way. Consequently, the administration and services costs due to the intervention from the third party can be significantly saved.
- *Improving the efficiency of business processes.* The elimination of the dependence on the intermediary can significantly improve the efficiency of business process. Take the aforementioned supply-chain procedure as an example. The financial settlement will be automatically completed in a peer-to-peer manner once the predefined condition is met (*e.g.*, the buyer confirms the reception of the products). As a result, the turnaround time can be significantly reduced.

Smart contracts are boosting a broad spectrum of applications ranging from industrial Internet of Things to financial services [2], [3], [4], [5], [6], [7], [8], [9], [10], [11]. Although smart contracts have great potentials to reshape conventional business procedures, there are a number of challenges to be solved. For example, even if blockchains can assure a certain anonymity of the parties of the contract, the privacy of the whole contract execution may not be preserved since all the transactions are globally available. Moreover, it is challenging to ensure the correctness of smart contracts due to vulnerabilities of computer programs to the faults and failures.

There are some recent studies on smart contracts. For example, [12], [13], [14] present comprehensive surveys of blockchain technology and briefly introduce smart contracts. The work of [15] provides an in-depth survey on Ethereum smart contract programming vulnerabilities while [17] presents a detailed survey over verification methods on smart contract languages. The work of [16] reports authors' experiences in teaching smart contract programming and summarizes several typical types of mistakes made by students. Ref. [18] presents an empirical analysis on smart contract platforms. Recent studies [19], [20] also collect some literature of smart contracts and present reviews while fail to discuss the challenges in this area. Moreover, the work of [21] presents a brief overview of smart contract platforms and architectures. However, most of existing papers fail to identify the rising challenges and give a comprehensive survey. For example, Ethereum can be used to conduct illegal business such as Ponzi schemes that were reported to defraud over 410,000 US dollars while few studies address this issue [22]. We summarize the differences between this paper and existing studies in Table II.

The objective of this paper is to conduct a systematic overview of technical challenges in smart contracts enabled by blockchain technologies. Contributions of this paper are highlighted as following:

- Important research challenges in the life cycle of smart contracts are identified.
- Recent advances in addressing technical challenges are summarized.

Table I. Acronym Table

Terms	Acronyms
Proof of Work	PoW
Proof of Stake	PoS
Practical Byzantine-Fault Tolerance	PBFT
Low Level Virtual Machine	LLVM
Convolutional Neural Network	CNN
Long Short Term Memory	LSTM
Ether	ETH
Bitcoin	BTC
Ethereum Virtual Machine	EVM
Unspent Transaction Output	UTXO
Internet of Things	IoT
Distributed Autonomous Corporation	DAC
Certificate Authority	CA
Delegated Proof of Stake	DPOS
WebAssembly	Wasm
Border Gateway Protocol	BGP

[1]Commonly used acronyms in this paper are listed in Table I

Table II. Comparison with related work

Research	Ethereum	Other platforms	Programming Languages	Other technical challenges	Technical advances	Rising challenges	Applications
[12], [13], [14]	✓	✗	✗	✗	✗	✗	✗
[15], [16]	✓	✗	✓	✗	✗	✗	✗
[17]	✓	✓	✓	✗	✗	✗	✗
[18]	✓	✓	✓	✗	✗	✗	✓
[19], [20], [21]	✓	✓	✓	✓	✓	✗	✓
This paper	✓	✓	✓	✓	✓	✓	✓

- A detailed comparison of typical smart contract platforms is made.
- Diverse smart contract applications are summarized.

Organization of this paper. Section II gives a brief introduction to blockchains and smart contracts. Section III then summarizes research challenges in smart contracts as well as recent technical advances. Section IV next compares typical smart contract development platforms. Section V categorizes typical smart contract applications. Finally, Section VI concludes the paper.

II. Overview of Blockchain and Smart Contract

Smart contracts are built upon blockchain technology ensuring the correct execution of the contracts. We first provide a brief introduction to blockchain technology in Section II-A. We then give an overview on smart contracts in Section II-B.

A. Blockchain

A blockchain can be regarded as a public ledger, in which all transactions cannot be falsified. Figure 2 illustrates an example of a blockchain. A blockchain is a continuously-growing chain of blocks. When a new block is generated, all the nodes in the network will participate in validating the block. Once the block is validated, it will be appended to the blockchain.

To validate the trustfulness of blocks, consensus algorithms are developed. Consensus algorithms determine which node to store the next block and how the new appended block to be validated by other nodes. Representative consensus algorithms include proof of work (PoW) [23] and proof of stake (PoS) and practical byzantine-fault tolerance (PBFT) [24], [25]. Consensus algorithms are usually done by users who first solve the puzzle (*i.e.*, PoW or PoS). These users are called *miners*. Each miner keeps a full copy of the blockchain. Different from PoW and PoS, PBFT requires a multi-round voting process to reach the consensus. The distributed consensus algorithms can ensure that transactions are done without the intervention of third parties like banks. As a result, the transaction costs can be saved. Moreover, users transact with their virtual addresses instead of real identities so that the privacy of users is also preserved.

In blockchain systems, it is possible that several nodes can successfully reach the consensus (*i.e.*, solving the puzzle) at the same time, consequently it can cause the bisected branches. To solve the disparity, a shorted side chain is desolated as shown in Figure 2 while the longest chain is selected as the valid chain. This mechanism is effective since the longer chain is more tolerant to malicious attacks than the shorter chain in distributed systems.

In summary, blockchain technology has the key characteristics of decentralization, immutable, persistency and anonymity [26], [27], [28].

B. Smart Contract

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

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

The whole life cycle of smart contracts consists of four consecutive phases as illustrated in Figure 3:

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

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