Reflections on Information Technology-Driven Future Industries (Postprint)

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Abstract

The 20th National Congress of the Communist Party of China has charted the course for the new-generation information technology industry, emphasizing high-quality development as the central theme and the construction of a new growth engine for this sector. The information technology domain features a massive market, intense technological competition, and exhibits greater monopolistic tendencies and technological exclusivity compared to traditional industries. Artificial intelligence, data-driven methodologies, and computational power have already precipitated profound transformations within the scientific community. The establishment of a novel technological system necessitates capitalizing on the invaluable opportunities arising from emerging applications. As a new wave of scientific and technological revolution and industrial transformation accelerates, accompanied by fundamental shifts in research paradigms, seizing the current strategic opportunity window for information technology development holds paramount importance for expediting the construction of a new development paradigm and strengthening the nation's position as a technological powerhouse.

Full Text

Several Thoughts on Information Technology Driving Future Industries

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The 20th National Congress of the Communist Party of China has charted the course for the new generation of information technology industries, emphasizing high-quality development as the central theme and calling for the construction of new growth engines for these industries. The information technology sector commands a massive market and features intense technological competition, exhibiting greater monopolistic tendencies and technological exclusivity than traditional industries. Artificial intelligence, data-driven approaches, and computing power have already precipitated tremendous transformations in the scientific community. Establishing a new technological system requires seizing the valuable opportunities that emerge with new applications. As a new round of scientific and technological revolution accelerates and the research paradigm undergoes profound changes, grasping the current opportunities in information technology development holds significant importance for accelerating the construction of a new development pattern and building China into a technological powerhouse.

Development Opportunities in Information Technology

The information technology field currently harbors enormous development opportunities. As new data mining and application algorithms advance, data-driven tools have become profoundly significant for numerous fundamental scientific research endeavors. For instance, the rapid development and application of artificial intelligence have provided tremendous impetus to natural sciences such as life sciences and materials science. However, the field also faces substantial challenges, most notably the gradual failure of Moore's Law. On one hand, information technology development demands more computing power; on the other, novel computing methods such as quantum computing and optical computing pose fresh challenges to our fundamental understanding of computation. When redesigning quantum computer systems, for example, we discover that we do not yet fully comprehend the nature of computation itself. This represents both a challenge and a significant theoretical opportunity within the information technology domain, particularly in computer science.

Artificial Intelligence as the Main Frontier Trend

The development and application of artificial intelligence have become the primary trend at the forefront of information technology advancement. AI's rapid development is producing major impacts on human society. Over the past five years, AI-related technologies have frequently been selected for MIT Technology

Review's annual "10 Breakthrough Technologies" list. For example, the 2023 list included "AI that makes images" and "The chip design that will change everything," while the 2022 list featured "The end of passwords," "AI for protein folding," "Proof of stake," and "AI-generated data," and the 2021 list highlighted "GPT-3," "Data trusts," "Digital contact tracing," "TikTok recommendation algorithms," and "Multi-skilled AI." These selections demonstrate that artificial intelligence plays a crucial role both in application domains and at the infrastructure level. On the application side, AI is making important contributions in numerous fields such as biology and computer graphics, with AI assistants being widely adopted. At the infrastructure level, the foundations supporting AI applications face many challenges, including how to better generate, manage, and protect data, and how to provide sufficient computing power. Overall, emerging AI problems are concentrated primarily in application and infrastructure domains, which constitute the current key research directions.

The iterative nature of AI development resembles Moore's Law—as the scale of AI models increases, their capabilities continuously improve, and this growth shows no signs of stopping. This rapid iteration not only enhances AI's own capabilities but also provides tremendous assistance to traditional industries and disciplines, as the availability of more data accelerates scientific research processes. Consequently, AI development has positive impacts on society as a whole.

Strengthening Academia-Industry Collaboration

While close connections exist between academia and industry in information technology, a gap remains between the issues that concern academia and those that actually matter in industry. Currently, there is an urgent need to extract key problems from industrial applications and feed them back to academia for research. Taking theoretical computer science as an example, this discipline primarily studies the feasibility of computation and largely forms the foundation of computer and information science. Theoretical computer science can be regarded as the fundamental laws of the computing and information processing world, analogous to objective laws in physics. Before computers were invented, theoretical computer science existed as a branch of mathematics, focusing on fundamental theories of computation, algorithms, and complexity. Many epoch-making innovations in computer invention, manufacturing, and algorithmic applications have been built upon its foundations. Therefore, theoretical computer science plays an important role in the field of computer science and stands at the frontier of interdisciplinary research between computer science and other disciplines.

As a methodological discipline, the value of theoretical computer science lies in computational thinking, which possesses strong universality and can intersect with computer science, economics, natural sciences, engineering, and other fields. It can propose new problems, perspectives, and solutions in complex scenarios that previously lacked descriptive language or were difficult to solve—this is meaningful not only for computation itself but also for the physical world and human society.

The matching between theoretical computer science and applications represents a very important frontier direction. In the past, theoretical computer science followed a pattern of theory first, then computers; computer behavior was set by humans and completely understandable. However, as computers become increasingly complex—including models like ChatGPT whose complexity increasingly approaches that of natural systems—experimental exploration is needed to verify theories, which can lead to inconsistencies with original theories. Therefore, how to better match theory with applications is a crucial frontier direction. When theory and application do not align, we need to develop new theories or better present the abstract nature of theoretical applications. For instance, in deep learning, applications are very cutting-edge, but theoretical understanding remains insufficient. Thus, we need to explore how to more tightly integrate theory and application—a direction that relates to both basic and applied research while also being driven by curiosity.

In 2020, Huawei established a Theoretical Computer Science Laboratory focusing on algorithmic complexity issues related to industrial applications. Theoretical computer science has great utility in industrial applications, particularly in Huawei's information and communication technology (ICT), optical, fast-pass, chip, system, application, and cloud service domains, where it has numerous applications.

Talent Cultivation as a Driving Force

China's scientific and technological development has entered a new stage where innovation becomes the primary driving force. Cultivating young scientific and technological talents with outstanding innovative capabilities on a large scale within China is the source of sustainable development for the country's scientific and technological endeavors.

Today, China's research institutes and universities have invested substantial resources in cultivating talent and tackling core technologies in basic theory. For example, in August 2019, the University of Chinese Academy of Sciences launched the "One Student, One Chip" program, which enables undergraduate students to participate in the entire process of processor chip design, production, and operation. This cultivates processor chip design talent with solid theoretical and practical experience, increases the scale of processor chip design talent cultivation in China, shortens the cycle from talent cultivation to deployment in research and industrial frontlines, and trains more urgently needed chip talent for the nation. The program has now conducted five sessions with over 2,000 participating students, initially forming a large-scale, high-quality processor chip design talent cultivation scheme.

The Microelectronics Thrust at Hong Kong University of Science and Technology (Guangzhou) has assembled teams and established a series of central research facilities, including materials and device micro-nano processing laboratories and an EDA research center, aiming to cultivate talent in microelectronics and promote more original technology output. Recently, the team has made progress and original discoveries in areas such as optoelectronic fusion chips, verification, and multi-processor high-speed simulation.

The Xiangshan open-source chip project, initiated by the Institute of Computing Technology of the Chinese Academy of Sciences, has attracted participation from domestic and international enterprises for joint development.

Open-Source Chips

Processor chips require coordination between software and hardware and are relatively complex to design. In recent years, the "open-source chip" design approach—applying the open-source software model to processor chip design—has represented a new direction in the field. For example, the RISC-V architecture has attracted global attention. Like the 5G standard in communications, we can unite global forces to jointly build a chip ecosystem and establish standards, with countries competing at the product level. Future chip design hopes to adopt more open approaches that fully leverage China's advantages of large market scale and abundant technical talent. In recent years, the open-source model has had a tremendous impact on the information field, and its influence will become even more profound in the next 3–5 years. While open-source software has already significantly impacted the information domain, this model is now penetrating the hardware field. For instance, in chips, the open-source chip trend will gradually strengthen. Although current open-source pre-trained models are still small-scale, as more people join, they may grow from small to large models. The open-source model will bring a series of profound impacts, including new approaches to data openness, sharing, and exchange. This influence extends beyond individual technical levels to transform entire technology research and development models and production relations. Therefore, we must not only recognize the impact of the open-source model but also continuously adapt to these changes to better advance information technology development.

IT Accelerating Natural Science Research

Artificial intelligence has become an important driving force for accelerating fundamental scientific research. Information technology has gradually permeated natural science research, with database and artificial intelligence methods becoming indispensable tools in daily scientific research.

In the field of data science, Turing Award winner Jim Gray proposed the fourth paradigm—data-driven scientific research following experimental observation, theoretical deduction, and computational simulation. In recent years, a fifth paradigm has been proposed, representing immersive embodied research with intelligence as the research objective, based on data science ontology. We can speculate that like the fourth paradigm, the fifth paradigm will also take data as its object; the difference is that the fifth paradigm focuses more on interaction between humans, machines, and data, emphasizing the integration of human decision-making mechanisms with data analysis, reflecting the organic combination of data and intelligence.

The combination of artificial intelligence and scientific research can help researchers improve the efficiency and accuracy of scientific research. For example, researchers with interdisciplinary backgrounds in mathematics, statistics, physics, and computer science can combine artificial intelligence with high-performance computing to provide powerful tools for molecular dynamics simulations and first-principles simulations. Through supercomputer acceleration, researchers have made major breakthroughs in atomic simulations, increasing simulation scale from the previous million-level to hundred-million-level and simulation time to the nanosecond level, which greatly benefits physics and materials science research. As science and artificial intelligence continue to combine, more breakthroughs will emerge.

In the future, data will become a fundamental resource for scientific research, and databases will become important scientific infrastructure, nurturing the growth of various disciplines like large scientific facilities. The materials science database (https://Atomly.net) recently released by the Songshan Lake Materials Laboratory in collaboration with the Institute of Physics of the Chinese Academy of Sciences uses high-throughput computing and information technology to bring high-quality scientific data to Chinese researchers. With the help of information technology, materials science has entered the "big data + artificial intelligence" era, breaking foreign monopolies in this field and creating high-quality foundational data and tools to broadly support the development of materials science in China, which have already begun to demonstrate effectiveness and substantially advance the field.

Interdisciplinary Development

Information technology, as a tool for natural science research, has been widely applied with remarkable results. Beyond this, the development of computer science itself has profoundly influenced natural science research. For example, the NP-complete problem in theoretical computer science was originally proposed only for computational complexity but is now widely applied in physics, chemistry, and biology. These disciplines use NP-complete problems to describe their laws and complexities as a tool for characterizing complexity. If a substance is NP-complete, it indicates relatively chaotic behavior; conversely, if it is not NP-complete, some internal patterns may exist. This interdisciplinary application fully demonstrates the important role of computer science in natural science research.

Viewing computer science from different perspectives, such as its integration with physics and economics, reveals its profundity, universality, and other advantages. The field of computer science is unique because of its rich color and diversity.

The development of information technology and computing has brought new essential concepts and measurement methods to natural science research, which is highly beneficial for scientific development. For example, research has proven that the computational complexity of calculating partition functions in a statistical physics system completely coincides with the phase transition lines of the physical system, indicating an intrinsic connection between computational complexity concepts and physical phase transitions. Similar interdisciplinary developments not only use information technology as a tool but also provide new essential concepts and methods for scientific research. Therefore, we need to explore more interdisciplinary research that integrates knowledge and methods from different fields to advance scientific development.

Early communication technology development was based on Shannon's information theory and Maxwell's electromagnetic field theory. Combining these two theories and using electromagnetic fields as information carriers can break the boundary between information and physics, improving communication efficiency. This connection is crucial and can bring more innovation and breakthroughs to information and communication fields.

IT Leading Industry Toward Digitalization and Intelligence

Artificial intelligence, data-driven approaches, and computing power have already caused tremendous transformations in the scientific community, and this transformation is quietly occurring in industry as well. As information technology continues to develop, industry is gradually shifting toward digitalization and intelligence. In this environment, the development of industry-academia-research relationships and changes in industry deserve focused attention.

AI Benefits for Industry and Downstream Applications AI development has brought clear benefits to industry and downstream applications. As the generality and capabilities of AI models continue to improve, the development costs for downstream applications have been substantially reduced. Previously, applying AI to traditional industries required professionals for data collection, labeling, and debugging at high cost. Now, the generality and intelligence of AI models have improved significantly, allowing everyone to train models with their own data; AI models' comprehension capabilities have also greatly improved, enabling them to interact and correct according to users' intentions. This widespread application of AI models has significantly reduced downstream application development costs—users can achieve desired effects through simple interfaces and prompts with minimal debugging and modification, greatly reducing costs and computing power consumption. Therefore, AI models have very broad prospects in industry and downstream applications.

The development prospects for artificial intelligence in natural science fields are very broad, with AI playing an obvious role as a tool for scientists. It will achieve more breakthroughs and progress in the coming years. In the next 3–5 years, AI is expected to make major breakthroughs in fields such as biology, physics, weather forecasting, and EDA integrated circuit design tools. Currently, there are already some preliminary results in these areas. For example, in biology, machine learning has been used to accelerate simulations; in physics and quantum physics, there are many application scenarios; and in EDA integrated circuit design tools, machine learning has demonstrated tremendous effects and efficiency improvements. However, these application scenarios still require further industrialization before they can be transferred to products.

Development Trends in Information Technology

Information technology is a field that can maintain continuous exponential growth—a trend not present in every research domain. Using aircraft engine thrust development as an example, from the Wright brothers' first flight in 1911 to the 1950s, aircraft engine thrust experienced exponential growth that once made moon landing seem possible, but this trend subsequently stagnated. In contrast, Moore's Law in information technology has persisted for nearly 60 years since the 1960s. Although Moore's Law appears to be approaching stagnation in reality, the data domain is exhibiting exponential growth, bringing new vitality to information technology. This growth trend is evident not only in hardware but also in data volume and other dimensions. This is a distinctive characteristic of the information technology field, and we must seize this opportunity to continuously leverage its advantages and promote integration with other fields.

Human society has entered the information age, but people's understanding, mastery, and application of information technology remain far from sufficient. In recent years, we have seen many amazing application scenarios (such as ChatGPT), but these are just the tip of the iceberg, with more new technologies and breakthroughs to emerge. From the perspective of the information technology field, the current era represents a golden age for academic research. Although Western countries are attempting to "decouple" from China, this compels us to develop our own original technologies and find alternative paths, presenting both new challenges and rare opportunities. In any new field, new paths always exist. Therefore, we must firmly seize this opportunity, actively explore research directions, and strive to promote the development of information technology.

Information science and technology represent a generic technology that serves as the underlying key technology for different scientific research and industrial applications. Consequently, the importance of information technology is self-evident—it provides assistance for both scientific research and industrial applications. Information technology has been widely applied in various fields such as healthcare, finance, and transportation, bringing convenience to people's lives and work. Simultaneously, information technology development drives innovation and transformation across industries. In the future, as information technology continues to develop, it will play an even more important role in contributing to human progress and development.

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