Application of Artificial Intelligence in Integrated Circuits

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Abstract. Integrated circuit and artificial intelligence technology are inseparable. Artificial intelligence technology depends on the learning ability and computing ability of computers and other machines. In this process, integrated circuits provide hardware support for the operation of artificial intelligence algorithms. For a long time, the application research of artificial intelligence technology in the field of integrated circuit mainly focuses on circuit fault analysis and artificial intelligence chips. Especially in recent years, due to the rapid development of technology, the combination of the two has become more closely, and more scientists and researchers have invested in the interdisciplinary research of the two disciplines. In this paper, the application of artificial intelligence technology in the field of integrated circuits is explored, that is, its applications in the three aspects of chip, integrated circuit fault diagnosis and circuit design optimization is discussed, and the relationship between artificial intelligence technology and integrated circuit is reflected. Finally, it is concluded that the cross research and application of integrated circuit and artificial intelligence technology will have an important impact on the level of science and technology and the level of human social life.

1. Introduction
Integrated circuit is a miniature electronic device or component, and it is also a way to miniaturize the circuit (mainly including semiconductor devices, but also passive components), which is usually manufactured on the surface of semiconductor wafers. Integrated circuit technology is applied in various industries, such as computer, medical, industry, etc., and it is also the basis of intelligent technology. In recent years, with the continuous development of artificial intelligence technology, the combination of integrated circuit and artificial intelligence technology has become one of the important development directions of information technology. Both promote and collaborate with each other. The continuous improvement of integrated circuits has promoted the rapid development of computer technology. Because the development of artificial intelligence technology depends on the advancement of computer technology, the development of artificial intelligence is very dependent on integrated circuits [1]. In addition, artificial intelligence algorithms must run on hardware, and the core of the hardware is integrated circuits (chips). Many mathematical models of artificial intelligence require a lot of data operations, such as recursion, circulation, convolution, etc. These algorithms run at different speeds on different types of integrated circuits, so many companies have begun or have developed chips that can specifically run artificial intelligence algorithms and realize artificial intelligence functions. On the other hand, artificial intelligence technology has been widely used in integrated circuit design, analysis, detection and other processes. It overcomes the limitations of human operations and helps designers and manufacturers to complete circuit design and manufacture more accurately and efficiently.
2. Development of integrated circuits
The idea of integrated circuits originated from the need to integrate electronic components and wires into a small carrier to reduce circuit area and volume. In 1946, the first electronic computer in the world was born in the United States, which covered an area of 150 square meters and weighed 30 tons. The circuit in it used 17468 electronic tubes, 7200 resistors, 10,000 capacitors and 500,000 lines, and consumes 150 kW of electricity. Large occupied area and inability to move became its most intuitive problem. To solve this problem, Bell Laboratories invented the first transistor in the world in 1947. Before this, to realize the current amplification function can only rely on the electronic tube with large volume, large power consumption and fragile structure. Transistors have the main functions of electronic tubes and overcome the above shortcomings of electronic tubes. Therefore, after the invention of transistors, the idea of semiconductor-based integrated circuits soon emerged. In 1960, the American Fairy Company produced the first monolithic integrated circuit which can be applied. This invention has become a milestone in the field of integrated circuit. From the earliest electronic tube to today’s integrated circuit, the integration of the circuits is getting higher and higher, and the functions that can be realized are becoming richer and richer. In 1960, the number of components contained in the integrated circuit was less than 100. Today, VLSI (ultra-large-scale integrated circuit) has been very popular, and tens of thousands to millions of transistors can be integrated on a silicon wafer with a few millimeters square, while the line width remains below 1 μm. With the development of integrated circuit, computer has become portable from the size of the original house.

In the information age, the development of integrated circuit is more and more fast, the global integrated circuit market is also developing rapidly. As figure 1 shows, in 2015, the global integrated circuit industry market size is $274.5 billion. By 2020, the global integrated circuit industry market sales have reached $361.226 billion, a year-on-year increase of 8.3%.

![Figure 1. Global IC market scale [2].](image)

3. Development of artificial intelligence
The term artificial intelligence was proposed by the Dartmouth Society in 1956. It is a discipline that uses computers to simulate certain human thinking processes and intelligent behaviors (such as learning, reasoning, thinking, etc.). Integrated circuit is the hardware foundation of artificial intelligence technology, with high integration and high performance. Its rapid development improves the computing and application capabilities of computers. Without the support of integrated circuits, artificial intelligence technology can only be on paper and cannot be physically realized. This makes it one of the core factors to promote the development of artificial intelligence technology. In turn, artificial intelligence not only expands human intelligence higher and further, but also extends many
integrated circuit design and application resources to areas that human cannot imagine and reach. In addition, artificial intelligence technology guides the direction for the development of integrated circuits. At present, deep learning computing needs huge amount of data, so memory and bandwidth have become the limitations of technology development, that is, the so-called memory wall problem. At the same time, deep learning requires high computing ability, which requires the improvement of hardware performance.

4. Application of artificial intelligence technology in integrated circuits

4.1. AI chips
The traditional CPU consists of the controller and the calculator. The data is calculated only by a separate ALU module, while the other modules are used to ensure that instructions can be executed orderly. This general structure is very suitable for the traditional programming calculation mode. However, because the calculation mode of deep learning does not require too many program instructions but requires massive data operations, this structure is no longer meet the needs. Especially under the limit of power consumption, the frequency of CPU and memory cannot increase unlimitedly to speed up the instruction execution, which leads to the development of CPU system encounters insurmountable bottleneck. The performance, delay and power consumption of AI chips have been greatly improved. The core of mainstream AI chips is to use MAC (Multiplier and Accumulation) acceleration array to accelerate the most important convolution operation in CNN (Convolutional Neural Network), which is dedicated to processing a large number of computing tasks in artificial intelligence applications (other non-computing tasks are still under the responsibility of CPU). Taking Google's TPU chip as an example, its processing speed is 15-30 times faster than CPU and GPU [3], and its power consumption efficiency is improved by 30-80 times. It can be seen from Table 1 that compared with high-power GPU, low-power TPU can achieve better rack-level density.

| Model             | mm² | nM | MHz | TDP | Measured 8b | TOPS/s | GP/s | On-Chip Memory | Die | DRAM Size | TDP |
|-------------------|-----|----|-----|-----|-------------|--------|------|----------------|-----|-----------|-----|
| Haswell E5-2699 v3 | 662 | 22 | 2300 | 145W | 41W | 145W | 2.6 | 1.3 | 51 | 256 GiB | 504W | 159W | 455W |
| NVIDIA K80 (2 dice/card) | 561 | 28 | 560 | 150W | 25W | 98W | -- | 2.8 | 160 | 8 MiB | 1838W | 357W | 991W |
| TPU               | NA* | 28 | 700 | 75W | 28W | 40W | 92 | -- | 34 | 28 MiB | 861W | 290W | 384W |

4.2. Fault diagnosis
In the design, test and operation of the whole integrated circuit, there will inevitably be fault problems. The circuit fault network is often fuzzy, that is, the fault phenomenon does not correspond to the actual fault. This also increases the difficulty of fault investigation. The introduction of artificial intelligence technology can determine the fault source and analyze the fault more scientifically, reasonably and accurately. Taking artificial neural network as an example, this method focuses on the self-organization and self-learning ability of information, and can store information distributively. It is suitable for dealing with complex situations in fault diagnosis that cannot be represented by explicit formulas, and can solve the problems caused by non-linearity, tolerance and feedback loops that are difficult to deal with in traditional models.

The processing units in the artificial neural network can be divided into three categories: input unit, output unit and hidden unit. The input unit receives the data and signals from the outside, and the output unit is responsible for the output of the processed results. The hidden unit is between the input unit and the output unit, which cannot be observed from the outside of the neural network system. Neuron processing units can represent different objects, such as letters, concepts, features, or
represent meaningful abstract patterns. The connection weights between neurons reflect the connection strength between network processing units, and the connection relationship between processing units reflects the representation and processing of information. Artificial neural network has the characteristics of non-programmable and adaptive information processing, which is a simplified and abstract simulation of human brain structure and operation mechanism. The core of artificial neural network is artificial neurons. Each neuron receives the input from other neurons, and then multiplies the received information by the assigned weight, and adds them to pass the final results to one or more neurons.

Figure 2 is a three-phase rectifier circuit. When the circuit fails, the neural network fault diagnosis method is used to sample the waveform of the output voltage. The sampled data will be used as the input of the neural network. After the neural network learning, the consistency of the input information and the fault element coding is built, so as to realize the fault judgment of the three-phase rectifier circuit [5].

By establishing artificial neural network for troubleshooting, the design, testing and operation of integrated circuit system can be promoted more efficiently.

4.3. Circuit design optimization

Circuit design often requires circuit designers to continuously simulate through previous design experience to find the maximum value of target parameters. In the traditional simulation optimization process, it is easy to have too many parameters and need multiple iterations, which further leads to a large amount of time spent in an optimization iteration simulation. Using machine learning technology, the design parameters are sampled before optimization, and the corresponding target parameters are obtained through circuit simulation. Figure 3 is a simplified flow chart for the application of machine learning in circuit design optimization. A machine learning model is established for the sampling results. The model realizes the circuit optimization by predicting the relationship between design parameters and target parameters. The advantage of this method is that the whole process requires only a few samples to establish a machine learning model, and then each optimization is generated by the model, and the prediction rate of the machine learning model is much higher than that of the simulation. Therefore, the time-consuming problem is solved, and the circuit design is faster and better optimized.
5. Conclusion
This paper analyzes the application of artificial intelligence technology in integrated circuits, and expounds from three aspects of artificial intelligence chips, circuit fault diagnosis and circuit design optimization. Firstly, the emergence and development of artificial intelligence chips means the vigorous development of artificial intelligence technology and integrated circuits, and also symbolizes the substantial increase in machine intelligence, laying the foundation for the development and improvement of information technology. Secondly, in the aspect of circuit fault diagnosis, artificial intelligence technology makes use of its advantages in calculation quantity, calculation speed and calculation accuracy, abstracts the human brain neural network from the perspective of information processing, establishes the model by artificial neural network learning, and then carries out pattern recognition to judge the cause and type of fault. Thirdly, the traditional simulation optimization process in circuit design optimization is improved, and the machine learning technology is used to establish a model for the sampling results. This cannot only improve the efficiency of design optimization and reduce the number and time of simulation, but also improve the compliance and accuracy of parameters, and save the energy consumption of computers. The application of these three aspects well reflects the relationship and development direction of complementary and coordinated development between artificial intelligence and integrated circuits. It can be predicted that with the deepening of artificial intelligence technology and the continuous improvement and optimization of integrated circuit hardware, in the future integrated circuit will be more intelligent, realize more technical functions, and bring more convenience to human life. The combined development of artificial intelligence technology and integrated circuits will also bring greater breakthroughs and improvements to the level of science and technology, and bring great contributions to social development.

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