Deyi Li and Yi Du

ARTIFICIAL INTELLIGENCE WITH UNCERTAINTY

SECOND EDITION

CRC Press
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A CHAPMAN & HALL BOOK

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National Defense Industry Press

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Deyi Li and Yi Du

Tsinghua University

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Preface to the Second Edition

Eleven years have elapsed since the first edition of *Artificial Intelligence with Uncertainty* came out. Reading the words written back then, I still feel warm hearted. The second edition is the result of the deepening of basic theoretical research on artificial intelligence with uncertainty, a coming together of cloud computing, big data, networking, and smart planet in the context of an Internet environment, creating a group intelligence through sharing and interaction in social computing. All these point to the fact that a new era has arrived after a half century of developments in which Turing computing has become Internet computing, and in which an artificial intelligence that simulated human thought processes through mathematical and symbolic logic became artificial intelligence with uncertainty.

Language is both the carrier of human thought and the accumulation of human intelligence. We believe that natural language should be the starting point for research into artificial intelligence with uncertainty. The qualitative concepts expressed by language values serve as the basis of human thought, which is random and vague. We explain the probability and statistics of fuzzy sets and type-2 fuzzy sets indicated by membership degree. When it comes to the dependence of fuzziness on randomness, we find that the subjection degree is neither precise nor subjective, but that it is uncertain and objective, which is elaborated on in this book.

A cloud model, especially a Gaussian cloud model, reflects the uncertainty of concepts in the process of human cognition through the three digital characteristics of expectation, entropy, and hyper entropy. A Gaussian cloud, composed of a large number of cloud droplets, comes from, but is different than, a Gaussian distribution. A series of interesting and meaningful statistical properties can be obtained through the "devil" of excess entropy. As for the high-order cloud model formed by increasing the order, a cloud droplets group can even transform from Gaussian distribution to power-law distribution in different orders, which this book explains quite clearly.

Physics can change the world. Atomic models and fields are physical perceptions of the objective world, which we introduced into a subjective perception of the world. The human brain is often called a small universe, which means that it is as rich and vast as the universe, a map of nature and society. Thanks to the support of cloud models, cloud transformation, cloud reasoning, cloud control, data fields, and topological potential, we come up with a physical method for cognitive computing. Through controlling a triple inverted pendulum, we present a variety of balancing patterns, explain the emergence of a spontaneous applause mechanism in concert halls, develop a wheeled robot to simulate different human driving behaviors, and develop a variable sized personalized mining engine in a cloud computing environment. These vivid cases give us a more profound understanding of artificial intelligence.

This book has been used as teaching material by more than 300 graduate students over six academic years at several universities—including Tsinghua University, Beijing University of Aeronautics and Astronautics, Wuhan University, Beijing University of Posts and Telecommunications, and PLA University—supported by course materials, a teaching website, and a teaching practice database. All the insightful queries and brainstorming that came out of the teaching process will not be forgotten.

Science is rooted in the discussion. Exchanging ideas is important for both authors and readers, in teaching and learning. We hope that more people will join in the exploration of artificial intelligence with uncertainty and experience its charm.

Deyi Li and Yi Du

Postscript to the Second Edition

It is gratifying that although *Artificial Intelligence with Uncertainty* has been in print for nine years, it still receives warm attention from readers. However, the authors have regretted that some of the content is still not accurate enough. With the rise of soft computing, semantic computing, granular computing, cloud computing, the Internet of Things, and big data over the years, the authors have had an urge to republish the book now and then. It was not until 2015 that they made up their minds to revise the book after carefully organizing their thoughts: replying to questions raised by readers and students; recalling discussions with, and doubts of, academic peers; and summarizing the latest work.

We have spared no effort to publish a book that will not only amuse readers, but will also enable those who are interested in duplicating the models, algorithms, and cases mentioned. We have also tried our best to make it an enjoyable read by making it interesting, vivid, and lively rather than creating a deductive encyclopedia, however abstruse the subject seems to be. To avoid it being too heavy, we have highlighted the original nature of our work, deleted some general mathematical and basic knowledge, and emphasized intelligent computing related to uncertainty, such as cloud computing, cloud transformation, big data, and social computing.

The revision of the book owes much to the arduous labor of the first author's postgraduate students, including Gan Wenyan and Liu Yuchao, who contributed to the preparation of some sections. The authors have benefited greatly from discussions with well-known professors, including Professors Kleinberg, Barabási, Mendel, Kai Huang, Lixin Wang, and others, and some young scholars, including Yu Liu, Changyu Liu, Kun Qin, Liwei Huang, Mu Guo, Wen He, Shuliang Wang, Liwei Huang, Xin Wang, and many more. Zengchang Qin, Gansen Zhao, Dongge Li, Yu Zhou, Yanwei Fu, and Yiran Chen revised the contents of this book. On the eve of republishing, hearty gratitude is extended to those helpful students and academic peers!

We are also grateful to our relatives. Thanks to their unremitting support and loving care we were able to finish this book successfully.

Sincere thanks are given to all who offered to help with the book!

Introduction

This book is concerned with uncertainty in artificial intelligence. Uncertainty in human intelligence and human knowledge is universal, objective, and beautiful but also difficult to simulate. The models and reasoning mechanisms for artificial intelligence with uncertainty are discussed in this book through cloud model, cloud transformation, data field, intelligent control, and swarm intelligence.

The authors' research have given this book a distinct character, making it valuable for scientists and engineers engaged in cognitive science, AI theory, and knowledge engineering. It is a useful reference book for university graduate students.

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Preface to the First Edition

It is often said that three big difficult problems remain unsolved in the world: generation of life, origin of the universe, and how the human brain works. This book addresses the third problem, and it studies and explores the uncertainties of knowledge and intelligence during the cognition process of human brain and how to use the computer to simulate and deal with such uncertainties.

Why does humankind possess intelligence? How does the human brain work? As the quintessence of hundreds of millions of years of biological evolution and millions of years of human evolution, how does the human brain process uncertainties? We don't know much about these very important and interesting questions.

If brain science explores the secrets of the brain via research on cells and molecules, if cognitive psychologists master the rule of the brain via observation on "stimulus-response" (i.e., "input–output"), then artificial intelligence, which has been researched on for nearly 50 years, tends to formalize representation of knowledge and use symbolic logic more often to simulate the thinking activities of human brain.

In the twenty-first century, we step into the Information Age, when the information industry leads the development of the global economy, and rapid development of information technology is changing the society we live in, including our work mode and lifestyle. Some say that an information industry and information technology–oriented knowledge economy era is announcing its arrival to the whole world. However, while we are enjoying the Internet technology and culture, we are also confronted with information overload; therefore, people are trying to find real information, the information they need, or even new knowledge from the ocean of data through artificial intelligence. Here, a most basic aspect of artificial intelligence is involved, that is, representation of knowledge. John von Neumann, the most influential scientist of the twentieth century, who made outstanding contributions to the development of electronic computers and was renowned as the "Father of the Electronic Computer," carried out in-depth studies on similarities and differences between electronic computers and the human brain, and he asserted in his posthumous work that language of the human brain is not a mathematical language.

Natural language is the basic tool of human mind. We think a very important entry point of research on artificial intelligence should be natural language, which is the carrier of knowledge and intelligence. The qualitative concept indicated by natural language value possesses uncertainty, especially randomness, fuzziness, and the relatedness between randomness and fuzziness. Exploring more deeply from such an entry point is exactly the artificial intelligence with uncertainty we are going to discuss.

This book discusses the objectiveness, universality, and positivity of the existence of uncertainty in human knowledge and intelligence; studies the mathematical basis, feature, representation, model, inference mechanism, certainty of the uncertain thinking activities of artificial intelligence with uncertainty; expands hierarchically from the cloud model used for qualitative and quantitative transformation and the physical method of cognition to data mining, knowledge discovery, and intelligent control; identifies the regularity in uncertain knowledge and intelligent processing; and finally forecasts the development direction of research on artificial intelligence with uncertainty.

In the past 10 years, supported by the National Natural Science Foundation of China, 973 Program, 863 Program, and the National Defense Pre-Research Foundation of China, we have completed some research on artificial intelligence with uncertainty, which seems to be reaching an organic whole, unifying many important but partial results into a satisfactory framework to explain how artificial intelligence with uncertainty explored and generalized the traditional artificial intelligence science.

Humans are born with the desire to seek knowledge and seek beauty. How do people process cognition? How do people try to use the theory of "beauty" to explain and simulate the cognition of humankind? This is exactly where our interests lie when we strive to make the exploration. The research subject of this book is very challenging and interesting, but the knowledge level and practical ability of the authors are limited, so the writing of this book is just an exploration and is the deepening of the research work. Inevitably, there are errors in the book, and we welcome readers to comment and point out any mistakes.

This book will be useful to scholars engaging in the study of cognitive science, brain science, artificial intelligence, computer science, and cybernetics, especially researchers and developers working on understanding and processing of natural language, intelligent retrieval, knowledge engineering, data mining, knowledge discovery, and intelligent control. Meanwhile, it could also serve as a teaching book or reference book for postgraduates of related majors in universities and colleges. It is hoped that there will be more people participating in the exploration of artificial intelligence with uncertainty. May our innermost sincerity and blessing be sent to you—for people who read this book by chance at a certain moment, it might be beneficial to your job and interest, which is exactly the glamour of knowledge and intelligence with uncertainty.

Deyi Li and Yi Du

Authors

Deyi Li earned his PhD in computer science at Heriot-Watt University in Edinburgh, U.K., in 1983. He was elected a member of the Chinese Academy of Engineering in 1999 and a member of the Eurasian Academy of Sciences in 2004. Dr. Li has published more than 100 papers on a wide range of topics in artificial intelligence. His other books include *A Prolog Database System* and *A Fuzzy Prolog Database System*.

Yi Du earned his PhD in computer science at PLA University of Science and Technology in Nanjing, China, in 2000. At present, Dr. Du is a senior engineer in network management in Beijing.

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Chapter 1

Artificial Intelligence Challenged by Uncertainty

During the rapid development of science and technology in the nineteenth-century Industrial Revolution, machines were employed to reduce manual labor or replace it altogether. In the twentieth century, advances in information technology, especially the advent of computers, produced machines that reduced or substituted for the work of the human brain, prompting the birth and rapid rise of artificial intelligence. In the twenty-first century, the widespread applications of the Internet and cloud computing, intelligent computing, sharing, interaction, and swarm intelligence have revolutionized people's lives, indicating the arrival of the new era of artificial intelligence.

Intelligence can be defined as wisdom and ability; what is called artificial intelligence (AI) is a variety of human intelligent behaviors, such as perception, memory, emotion, judgment, reasoning, proof, recognition, understanding, communication, design, thinking, learning, forgetting, creating, and so on, which can be realized artificially by machine, system, or network.

Over the past 60 years, there has been great progress in AI. However, machine intelligence, built on the basis of certainty or accuracy, is severely limited by its formal axiom system, the precision of which is unable to simulate the uncertainty of human thought processes.

Thinking is the human brain's reflection on and recognition of the essential attributes and the inner linkages of objective things. Language is the carrier and expression of human thought. Human intelligence differs from machine intelligence and even other forms of biological intelligence, in that only human beings are able to carry forward, through oral and written languages, knowledge accumulated over thousands of years. The uncertainty of intelligence is inevitably reflected in language, knowledge, thought processes, and results. Therefore, this book focuses on the study of uncertainty: its representation, reasoning, and simulation of human intelligence; on basic certainty in human intelligence; and how uncertainty challenges artificial intelligence.

1.1 The Uncertainty of Human Intelligence

1.1.1 The Charm of Uncertainty

In the nineteenth century, the deterministic science represented by Newton's theory created a precise way to describe the world. The whole universe, as a deterministic dynamic system, moves according to definite, harmonious, and orderly rules that can determine future events. From Newton to Laplace, and then to Einstein, they depict a scientific world that is completely determined. Followers of determinism believe that uncertainty is only due to people's ignorance of, not to the original look of things. If we are certain of the initial condition of things, we can completely control their development.

For a long time the deterministic view of science limited how people understood the universe. Despite living in a real world full of complex and chaotic phenomena, scientists only saw the predictable mechanical world with its structure and operational rules. They considered uncertainty insignificant, excluding it from the scope of modern scientific research.

According to the deterministic view, the present state and development of the universe were decided in its early chaotic stage. Things as large as changes in the world's landscapes, or as small as personal ups and downs, were determined 10 billion years ago. Nowadays people disagree with this point of view because the reality of uncertainty is all around us. However rich one's knowledge and experience, it is impossible to predict what will happen in life, for example, who will win an Olympic medal or how likely one is to win the lottery.

With developments in science, deterministic thinking has come up against insurmountable difficulties in an increasing number of research areas, such as the study of molecular thermal motion. With the multiple degrees of freedom that a large number of factors introduced, single-value deterministic theory is not only unable to solve the inherent complexity of the system, but the complexity of the system will also result in fundamental changes in things. Even though the full trajectory of particles and the interactions between them can be precisely determined, it is hard to know the exact behaviors forming the whole. Thus, in the late nineteenth century, Boltzmann, Gibbs, and others introduced the idea of randomness into physics and established statistical mechanics. Statistical mechanics states that, for a group of things, Newton's laws can only describe a general rule; individual members of the group cannot be described definitively, but only in terms of their behavior, that is, their "probability."

The emergence of quantum mechanics had a further impact on deterministic theory by showing that uncertainty is an essential attribute of nature. Quantum mechanics studies the movement of groups of atoms or particles. Because the particles are very small, observation, however it is conducted, interferes materially with the object it is observing. We cannot accurately determine the coordinates and momentum of the particles at a given moment. The more certain the coordinates of the particles, the more uncertain their movement, hence the "uncertainty principle" proposed by the German physicist Werner Heisenberg. The uncertainty of the objective world is not a transitional state caused by our incomplete knowledge, but is an objective reflection of the essential characteristics of nature.

Scientists have also admitted that although what we call scientific knowledge today is a collection of statements with different degrees of certainty, all our conclusions about science contain a degree of uncertainty. In the twentieth century, the philosopher Karl Popper described physical deterministic theory in his book *Objective Knowledge: An Evolutionary Approach* [1] thus: "I believe Peirce was right in holding that all clocks are clouds to some considerable degree—even the most precise of clocks. This, I think, is the most important inversion of the mistaken determinist view that all clouds are clocks." Cloud symbolizes the chaos, disorder, and unpredictability of uncertainties, such as climate change, ecosystems, celestial movements, Internet computing, human mental activity, and so on. Whereas the clock is accurate, orderly, and highly predictable. The Cartesians believe that all our actions merely seek to convert the cloud into a clock. Those who believe in nondeterminism think that in the physical world not all events are determined accurately in advance, in every detail. Many scientists and philosophers agree with the view that uncertainty is the objective state of human cognitive ability.

Clouds formed by drops of moisture in the sky take on form if viewed from afar but are shapeless when viewed close to. Their form is elegant and changeable, showing different poses, sometimes like blossoming cottons, sometimes rushing down like water, light or dark, curled or stretched and carefree. They float in the air, coming together and parting, changing all the time, stimulating poetic imagination, hence the use of the term "cloud computing" to describe the uncertainties of the Internet.

The undulating contours of hills, winding coastlines, and rivers extending in all directions are not smooth but uncertain irregular shapes whose size, length, and area change according to the scale on which they are being measured. Once the scale is determined, the measured value can be determined; within a certain range, there is a power function relationship between the scale and the measured values. The length of a coastline can only be determined by the device used to measure it. This is the uncertainty of measurement.

A line group is a point when viewed from a distance, a three-dimensional sphere when looked at closer; it becomes a curve when you approach the surface, and a one-dimensional element when looked at more closely; a careful look shows a three-dimensional cylinder then a two-dimensional plane when looked at even more closely. If you examine a fiber of wool it is one-dimensional, which becomes a three-dimensional cylinder if you look closer. If you look at the Earth from outside the galaxy it is a point; seen from within the solar system the Earth's orbit is elliptical; viewed on a plane the Earth is a two-dimensional surface. If you stand in the desert what you see will be completely different to what you see when standing on a small hill. This is the uncertainty of system dimension.

It is difficult to accurately represent the uncertainties of relationships between variables using analytic functions. Examples where x_i is a controllable variable with a specifiable value within a particular range, and y_i is a random variable with probability distribution include agricultural production and fertilizer (y_1, x_1); blood pressure and age (y_2, x_2); and strength and fiber length (y_3, x_3). There are many more variables or random variables that are not entirely independent of, dependent on, or associated with each other. This means the relationship between variables is uncertain.

You might inherit your grandfather's nose and your grandmother's earlobe; your sister may have eyes like her uncle; both of you might have the same forehead as your father. This is genetic uncertainty.

Particle collisions lead to the random orbital motion of particles. The course of this motion has a statistical self-similarity, that is, amplification of some small part of it may have the same probability distribution as that of some larger part. This is the uncertainty of movement.

The objective world is uncertain. The objective world mapped in the human brain is a subjective world, which should also contain uncertainty. Human cognitive processes therefore inevitably involve uncertainty.

Existence and thinking have an identity. When thinking abstraction, imagination, and randomness are hugely important because they lead beyond more existence to intuition, association, analogy, and sudden enlightenment in human intelligence, uncertainty in divergence and convergence, and creation. Creation has no definite pattern.

Speech and written language are two of the four major milestones in human civilization. Spoken language symbolizes an external object and written language is a code; both convey information. Language, especially in its written form, is passed on through the generations. The uncertainty of the objective world creates the uncertainty of natural language. The limitations of individual cognition make people describe the objective world in uncertain terms, which will be reflected in their language. The differences in people's cognitive abilities are also reflected in their different descriptions of the same event. Uncertainty, which is an essential feature of human cognition, is thus naturally reflected in language.

There is no fixed structure for the organization of language, any more than there is a fixed order for the expression of thoughts. Language consists of sentences.

A sentence can have different meanings in different contexts and situation. The basic elements in a sentence are linguistic values corresponding to different concepts. Generally, nouns are used to express concepts and the predicate expresses the relationship between concepts. Concepts and predicates have an uncertainty. Uncertainty in language does not impede our understanding; rather, it allows for the infinite possibilities of imagination. The Tang Dynasty poet Wang Bo paints a beautiful picture with the lines: "The proud eagle flies high in the sky, with rosy clouds floating alongside; the river runs away off to the horizon, reflecting the same tint in the blue sky." Cao Xueqin's "her two eyebrows, which seemed to knit and yet not to knit, and opening wide those eyes, which seemed to stare and yet not to stare," depicts Lin Daiyu's sick state and her aesthetic look. In these examples there can be no numerical substitutions.

Common sense is the abstraction of common knowledge, which includes many uncertainties, but it is also knowledge that is obvious. For example, people distinguish cups, plates, and bowls according to their size and use: a cup can be filled with water, a plate with rice, a bowl with soup; a cup has a handle but a plate does not; a bowl has an edge. But in terms of how we understand cups, plates, and bowls, there is no absolute ratio between width and height.

Common sense is different from professional knowledge because of its universality and directness. It may lack the depth and systematic nature of professional knowledge. It is largely relative, changing in accordance with time, place, and people. This is the uncertainty generated by relativity.

There was once a common understanding in AI that the essential distinction between human and machine was the possession or lack of common sense. Whether or not AI can eventually be achieved depends on whether human common sense can be realized. The uncertainties of cognition arise from the uncertainties of the objective world. Phenomena described as certain or regular will only occur under particular conditions, and will exist only partially or for a short time. Although many researchers in the natural sciences of physics, mathematics, and biology, and the social sciences of philosophy, economics, society, psychology, and cognition are involved in the study of certainty, hardly anyone challenges the essential uncertainty of the world. An increasing number of scientists believe that uncertainty is an essential element of the world, and that the only certainty is actually uncertainty!

Against this background, the science of chaos, the science of complexity, and AI with uncertainty have undergone rapid development, with the uncertainties inherent in common sense becoming a fruitful area for AI research.

Acceptance of the existence of uncertainty does not mean that we have to stop looking for basic, deterministic solutions, but we must remember not to draw premature conclusions when we have not fully understood the facts. Speculating arbitrarily on certainty will prevent us from finding effective solutions. Moreover, faced with complex situations, accepting the existence of uncertainty will help us keep an open mind, maintain a positive attitude, stimulate creative thinking, and promote scientific progress.

Cognitive uncertainty inevitably leads to research on artificial intelligence with uncertainty. A priority for AI scientists is how to represent and simulate the uncertainty of human understanding of the world, to enable the intelligence of machines, systems, or networks [2]. In this book, we start with the representation of uncertain knowledge, and propose a cognitive model–cloud model for qualitative–quantitative dual transformation, establish physical methods for the discovery of uncertainty knowledge and make use of cloud computing, natural language understanding, image recognition, data mining, intelligent control, social computing, and so on.

1.1.2 The World of Entropy

The first law of thermodynamics states that any thermodynamic process in nature must comply with the law of energy conversion and conservation. The modern post-industrial age—with the rapid development of science and technology, population growth, the increasing scarcity of water resources, worsening desertification, and excessive consumption of a variety of nonrenewable energy resources—gives us cause to think seriously about the future of mankind, of nature, and about fundamental questions of sustainable development. There always seems to be an invisible hand functioning, which might be entropy at work. Entropy is at the heart of the second law of thermodynamics, which dates back to the nineteenth century. In 1854, the German physicist R.J. Clausius first proposed the concept of entropy, ΔS, when studying thermodynamics, which is defined as

$$\Delta S = \frac{\Delta Q}{T}$$

where
 T is temperature
 Q is heat

In isolated systems, thermal molecular motion always goes from a centralized and orderly arrangement to a dispersed, chaotic state. Entropy represents the evenness of energy distribution in space and increases with the evenness of energy distribution. In the spontaneous transformation of a system from order to disorder, entropy always increases, which is represented by $\Delta S \geq 0$. When entropy reaches its maximum value in a system, the system enters a state of energy balance. At this moment, no further work is done by free energy within the system; the whole system is in a state of equilibrium. According to the second law of thermodynamics, without consumption or other change in a force, it is impossible for heat to flow from a low to a higher temperature.

This law states that mechanical energy is transformed into internal energy due to friction, viscosity, and other factors, and that the transformation is irreversible.

Heat is always transferred from an object with a higher temperature to one with a lower temperature, but not in reverse. The free expansion and diffusion of gas is also irreversible. For example, if you put a glass of hot water in the room and regard the room and the glass as an isolated system, the heat of the water will be distributed until its temperature is the same as that of the room, then the process of heat exchange stops. The heat spread into the air cannot automatically regather in the glass to boil the water again. In nature, towering majestic mountains become gravel rocks after many years of weathering, graceful flowers wither and are buried in dust. Entropy plays a role in this process.

In 1877, Boltzmann proposed an equation for entropy:

$$S = k \ln W$$

where

k is Boltzmann's constant

W is the number of microstates corresponding to a macroscopic state, that is, the thermodynamic probability of the macroscopic state

Entropy is proportional to the logarithm of the thermodynamic probability. The greater the thermodynamic probability, the more chaotic the system is. Therefore, thermodynamic entropy is a measure of the disorderliness of a system.

In 1948, Claude E. Shannon introduced the concept of information entropy, that is, the definition of probability entropy.

Let X be a system composed of n events $\{X_i\}$ ($i = 1, 2, \ldots, n$). Consider the event X_i with probability $p(X_i)$, then the information entropy (probability entropy) is defined as

$$H(X) = -\sum_{i=1}^{n} p(X_i) \log p(X_i)$$

Information entropy describes the average uncertainty of events occurring in the event set X. The higher the entropy, the greater is the degree of uncertainty. In the field of information, entropy is a measurement of the uncertainty of the system state. Here, "state" is not limited to thermodynamic systems but it extends the definition of entropy. In the formula for calculating entropy, if we use 2, 10, or e (i.e., 2.71828…) as a base, the units of information entropy are called bit, hart, and nat, respectively. When the probabilities of events in X are equal, information entropy reaches its maximum value. Shannon's contribution was to show that bits become the basic unit in the process of information transmission, referring to the uncertainty of the communication process.

When the basic concept of entropy was introduced into thermodynamics, physics was expanded beyond Clausius' proposition. By the 1990s the definition of entropy had been further generalized with thermo-entropy, electronic entropy, mobile entropy, vibration entropy, and self-spin entropy in statistical and quantum physics; in other areas there was topological entropy, geographic entropy, meteorological entropy, black-hole entropy, social entropy, economic entropy, anatomical entropy, spiritual entropy, cultural entropy, and so on.

Einstein defined entropy as the essential principle of all sciences. Originally used for the measurement of evenness of distribution, it then became a measure of the level of disorderliness, and further of uncertainty. It is therefore inevitable that it should be introduced into the field of artificial intelligence. As an important measure of uncertainty, entropy is a key parameter in the study of artificial intelligence with uncertainty. This book introduces entropy into the study of the cognitive model–cloud model, for qualitative–quantitative dual transformation and further proposes the concept of super-entropy.

1.2 Sixty Years of Artificial Intelligence Development

Since ancient times, humans have dreamed of artificially based intelligence, with relevant folklore dating as far back as 200 BCE. In the ancient Egyptian city of Alexandria, Heron probably invented the earliest intelligent machine in a number of automatic machines to ease manual labor, such as worshippers in the temple automatically obtaining the required amount of holy water by inserting coins into a slit; a gate opening automatically when the sacrificial fire was lit; and two bronze statues of priests standing on the sacrificial altar raising pots to pour holy water into the fire.

1.2.1 The Dartmouth Symposium

1.2.1.1 Collision between Different Disciplines

In June 1956 at Dartmouth, New Hampshire, four young scholars, John McCarthy, Marvin Minsky, Nathaniel Rochester, and Claude Shannon, organized a 2-month Dartmouth Summer Symposium on simulating human intelligence with machines. They invited 10 scholars from various fields, including mathematics, neurophysiology, psychiatry, psychology, information theory, and computer science. Each discussed their own research focus from the perspective of their individual discipline, which led to intense intellectual clashes.

The highlights of the Dartmouth Symposium were as follows: Marvin Minsky's Snarc, the stochastic neural analog reinforcement calculator; Alpha-Beta searching method proposed by John McCarthy; and the Logic Theorist, presented by Herbert Simon and Allen Newell, which proved a mathematical theorem [3].

While working on the cognitive process of proving a mathematical theorem, Herbert Simon and his colleagues found a common law. First, the whole problem is broken into several subproblems, then these subproblems are solved using substitution and replacement methods in accordance with the axioms and proven theorems. Based on this, they established the heuristic search technique for machines to prove mathematical theorems. Using the Logic Theorist program they proved a number of theorems from Chapter 2 of Russell and Whitehead's *Principia Mathematica*. Their work was regarded as a major breakthrough in the computer simulation of human intelligence [4].

Although the scientists present at the symposium had different perspectives, they all focused on the representative form and cognitive laws governing human intelligence. Making full use of the mathematical logic and computing capabilities of computers, they provided theories on formalized computation and processing; simulated some basic human intelligence behaviors; and created artificial systems with some sort of intelligence, enabling computers to complete work that could previously only be accomplished by human intelligence.

The Dartmouth Symposium marked the birth of AI, with John McCarthy (known as the Father of AI) [3] proposing the term "artificial intelligence" as the name of the new cross-discipline.

1.2.1.2 Ups and Downs in Development

In today's world intelligent machines, intelligent communities, intelligent networks, and intelligent buildings are everywhere and AI-related research is going on in almost every university. The development of AI has been far from smooth, however, with many controversies and misunderstandings along the way.

In the early 1980s, mathematical logic and symbolic reasoning became the mainstream of AI, and programming languages such as LISP and PROLOG were favored throughout the world. A Japanese initiative, called Fifth-Generation Computer Systems (i.e., computer systems processing knowledge and information), pushed AI research to a new high. However, the much anticipated "Fifth-Generation Computer" failed to go beyond the structural framework of the Von Neumann system and still used a program and data. It could not therefore realize a human–machine interaction through image, sound, and language in a natural way, nor could it simulate human cognitive processes.

Research on neural networks (i.e., NNs) had also boosted AI development. In the early 1940s, an artificial neural network (i.e., ANN) method was proposed by some scholars. In 1982, John J. Hopfield suggested using hardware to realize ANN [5]. In 1986, David E. Rumelhart and others put forward the Back Propagation algorithm in multilayered networks, which became a milestone in NN development. At that time, people expected that "thinking in images" could be processed through a biological, artificial neuron model that would simulate human visual and listening senses, and understanding, instinct, and common sense. Over the following two decades there was great enthusiasm among scholars for research on artificial neural networks, but the achievements fell short of expectations, both in theory and in applications, until deep belief network was proposed by Geoffrey Hinton in 2006. Since then a growing number of researchers, led by Geoffrey Hinton, Yoshua Bengio, and Yann LeCun, have engaged in related work on deep learning in a second wave of development on neural networks. Due to its advantages for discovering intricate structures in large data sets, deep learning has brought about breakthroughs in speech recognition, image analysis, text mining, and many other domains, greatly promoting the development of artificial intelligence.

In the 1970s AI, space technology, and energy technology were regarded as the top three technologies in the world. In the new century, with the extensive penetration of information technology into the economy, society, and everyday life, there is an increasingly urgent demand for machines that can simulate human intelligence. People began to question the Von Neumann architecture and seek new structures, like the Internet and quantum computers. AI was considered in a broader context. Cloud computing is widely used today, with the "Internet of people" and "Internet of things" becoming part of the infrastructure of human life and production. Swarm intelligence led by sharing and interaction have moved AI to a new stage.

1.2.2 Goals Evolve over Time

Over the 60 years of the development and growth of AI, the academic community has held various views on the goals for AI research.

1.2.2.1 Turing Test

The 100th anniversary of the birth of British mathematician, Alan Turing was marked in 2012. In 1950, he had proposed a test to determine whether a machine had human intelligence, which became a widely acknowledged AI test standard known as the Turing Test. The standard states that if the actions, reactions, and interactions of a machine are the same as those of a human being with consciousness, then it should be regarded as having consciousness and intelligence. To eliminate bias in the test Turing designed an imitation method. A human interrogator, separate from the machine, asks various questions of both a human and the machine. In a given period of time, the interrogator judges which answers came from the human and which from the machine. A series of such tests were devised to test a machine's intelligence level.

Some scholars argued that such machine intelligence was still far behind a human being. Let us imagine a machine engaged in a conversation with a human. However smart it is, the machine cannot have the same common sense as a person, nor can it consistently apply correct and special pronunciation, intonation, and emotion. It cannot react to different situations arising in the conversation process according to context. In this sense, the machine is not exhibiting human intelligence, even that of a child.

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