The Development of Ideas on Computable Intelligence

ZHANG Yinsheng,Guizhou Minzu University ;
CAI Shushan,Guizhou Minzu University
Translated by MIN Qiang

Abstract: This paper sums up the fundamental features of intelligence through the common features stated by various definitions of "intelligence": Intelligence is the ability of achieving systematic goals (functions) of brain and nerve system through selecting, and artificial intelligence or machine intelligence is an imitation of life intelligence or a replication of features and functions. Based on the definition mentioned above, this paper discusses and summarizes the development routes of ideas on computable intelligence, including Godel's "universal recursive function", the computation activities of "selection", recursive function and Turing machine, mathematical expression of computable intelligence, core nature of computable intelligence, and computability and strong artificial intelligence. At the end of this paper is the conclusion drawn by the authors.

Key Words: intelligence; strong artificial intelligence; Turing machine; computability; recursive function

1. The Fundamental Features of Universal Intelligence

There are many definitions of "intelligence" and "artificial intelligence(AI)". "AI" means man-made intelligence. The characteristics of AI's "intelligence" should be the same as the characteristics of individual "intelligence", and AI's "intelligence" is only a kind of implementation result made by another implementation

---

Authors: ZHANG Yinsheng: Male, the Han nationality, born in Laiyang City, Shandong Province, Doctor of Philosophy of Science and Technology, the Research Fellow of Institute of Scientific and Technical Information of China (ISTIC), the Adjunct Professor of Guizhou Minzu University, Master's Supervisor (Beijing 100038);
CAI Shushan: Male, the Han nationality, born in Guiyang City, Guizhou Province, Doctor of Philosophy, the Dean and Professor of College of National Culture and Cognitive Science of Guizhou Minzu University, Professor of Department of Psychology of Tsinghua University, Doctoral Supervisor, the Co-first Author and Corresponding Author (Beijing 100084).
Fund: The Major Project of National Social Science Fund—"The High-Order Cognitive Research on Hierarchy of Language, Thought and Culture" [Item No.:15ZDB017]; "The Neural Mechanism Research on Brain's Processing of Non-literal Language of Chinese (language)" [Item No.: 14ZDB154]

method. These are basic logic and common sense. Moreover, there is also a related definition called "universal intelligence", which attempts to define the common features of intelligence between "intelligence" and "AI". Therefore, under the circumstances of having a common view on the definitions of "intelligence", there is no question of acquiring a common view on the understanding of the concepts of "AI" and "universal intelligence".

"Intelligence" can not be defined and explained randomly. When people talk about "intelligence", what they are talking about is with some degree of certainty. The features of that certainty and the common features described by various definitions of "intelligence" are able to be abstracted. Therefore, it is necessary to abandon the practice that to understand "intelligence" absolutely based on experience due to ambiguous definitions or different understandings of "intelligence", because that practice only put the so called features of "intelligence" together but failed to make any further unification and abstraction of the definitions and understandings of "intelligence", or to demonstrate the common features from that features based on logic.

Some commonsense documents or conclusive philosophical documents summed up the definitions of "intelligence", and we tried to abstract the common features defined commonly by various definitions of "intelligence" from the synthesis of those concepts.

Gregory (R. Gregory, 1994) summed up the core feature of "intelligence" as natural selection, which is the original understanding of the concept of "intelligence" [1]. At the very beginning, the concept was to describe human beings (animals will have some lower-level features of intelligence) in order to distinguish the essential features of human beings from other animals—that is why we call human beings as homo sapiens. The common view in the field of biology is that intelligence, as the product of evolution, is the manifestation of natural selection. In English, natural selection can not only be understood as the selection of species' adaptability in natural world but also can be understood as making selection naturally, which is also the actions of selection of human beings (or organisms) in natural environment. Therefore, intelligence, in essence, is natural selection. That conclusion is made by the understanding of "intelligence" in the field of life science. Sterrett (S. Sterrett, 2002) supports the viewpoint that "intelligence is selection"[2].

Now people is considering to broaden the use of "intelligence" to non-living field. Whether the robots have intelligence or not? If they do have intelligence or suspected features of intelligence, whether there is any differences between robots' intelligence and human beings' intelligence? And what are the differences? Sterrett summed up the discussion of those issues[3]. This paper defined the intelligence of robots as the behavior that improper response, under unfamiliar circumstances, will be replaced by more proper response. In that definition, the behavior means an action that can make improvement, realize optimization and evolve itself according to specific environment.

In the field of AI, there are many definitions of intelligence. Sterrett and Norvig (S. Sterrett and P. Norvig, 1995) summarized those definitions[4].

Form 1. The Summary of Definitions of AI[5]

	I (do not emphasize reason)	II (emphasize reason)
A (do not emphasize action)	A machine that can think like human beings	A system that can think rationally
	A new exciting endeavor---to make computers think… The full literal meaning: a brainy machine. (Haugeland, 1985) [To make it automated] activities related to humans' thoughts, such as decision-making, problem solving and learning. (Belman, 1978)	Using calculation models to study metal activities. (Chaniak & McDemott, 1985) The study that can make having consciousness, conducting inference and taking action possible. (Winston, 1992)
B (emphasize action)	A system that can act like human beings.	A system that can act rationally
	A kind of skill: to create machines that can carry out instructions which can only be completed by human beings when they are using their intelligence. (Kuzwell, 1990) To study how to make computers to do things that currently human beings can do better than computers. (Rich & Knight, 1991)	Computational intelligence studies how to design intelligent agents. (Poole, etc., 1998) What AI cares about is the intelligent actions of artifacts. (Nilsson, 1998)

To find out the common features between organisms' "intelligence" and machines' "intelligence", the concept of "universal intelligence", which can be used in both living world and non-living world, was put forward[6]. It defines intelligence as "intelligence measures an agent's ability to achieve goals in a wide range of environments".

We can find that most of definitions of Form 1 are very empirical and they lack abstractions of features, while Sterrett (S. Sterrett, 2002), Legg and Mutter (S. Legg and M. Hutter, 2007) abstracted common features between machine intelligence and universal intelligence[7]. However, both Form 1 and Srerrett have not fully accepted or put forward Gregory's definition that "intelligence is to select"[8]. In definitions of different items, Legg and Hutter pointed out that agent was to put current input into memory for consideration to make next selection[9]. Therefore, Legg and Hutter accepted Gregory's viewpoint by and large.

Therefore, we can accept the viewpoints of Gregory, Legg and Hutter, and abstract the definitions of AI in Form 1 as well as machine intelligence actions put forward by Gregory so that we can have a concise (universal) definition of "intelligence" that can be used both in the fields of human beings and machines--- "intelligence is to select"(the base of the ability of selecting, of course, is a kind of "intentionality" that having goals, which is the ability of achieving goals mentioned by Russell and Norving). That is essential abstraction and concise expression of common features of the definitions of "intelligence" (of both living objects and non-living objects).

2. The Interpretation of Turing Machine——the Implementation Model of Intelligent Machines

In consideration of the common features of both human beings and machines, it is the dream of human beings to make machines intelligent, and Turing machine is the mechanical implementation of that dream. There were some intelligent machines in history. For example, by finishing calculating, an abacus will have intelligence to some extent, so do mechanical computers (like the ones invented by Charles Babbage). However, those are all living examples of the implementation of intelligence, not the universal models of mechanical implementation of intelligence, which are the models that can depict all the theories (expressions) of mechanical implementation of intelligence.

In the papers of Intelligent Machinery[10] and Computing Machinery and Intelligence[11], A. M. Turing put forward an ideal that machines could have the intelligence owned by human beings. Although Turing admitted that Turing machine, as a model to implement intelligence, designed by himself has some unsolvable problems(like paradoxes, Hilbert's tenth problem, etc.), those problems are also unsolvable for humans from the viewpoint of this paper(if people can solve those Turing's unsolvable problems by means of paradox solving, such as axiomatic set theory, computers, of course, can also solve those problems by those means). Therefore, Turing machine has provided mechanical methods of intelligence implementation for dealing with discrete variable at least.

A Turing machine(M) is a 6-tuple:[12]

M = < Q,∑ ,Γ ,δ ,q0 ,F >

In which:

Q: finite state set, like q1~q7 in Form 2.

∑ : inputted alphabet, like 1, 0 in Form 2 (exclude the symbol B that indicates blank space).

Γ : alphabet carried by the data, like B, 1, 0 in Form 2 (include the symbol B that indicates blank space), ∑ (Γ .

δ : transfer function, like the function of the instruction set of (Q - F)× Γ (Q× Γ × { L, R, S } in Form 2; L, R, S respectively indicates left, right and stop.

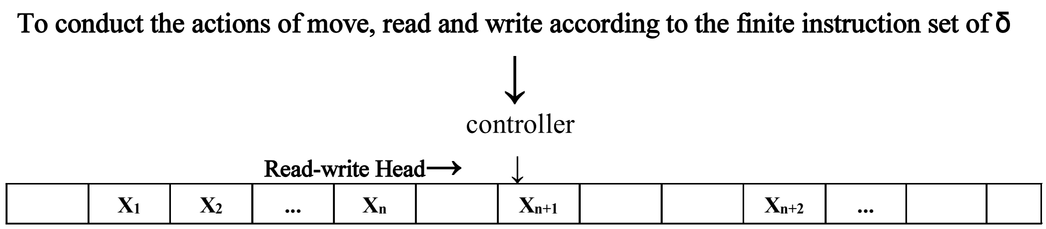
q0: original state, like q1, q0(Q in Form 2.

F: stopped state, F(Q, Accept(F, Reject(F;(Q - F) indicates various states that won't appear in F before (so that F should be deleted.

Accept: accepted state, one of the final states (as for the final character of the inputted character string), which indicates the Turing machine accept the character string.

Reject: rejected state, one of the final states (as for the final character of the inputted character string), which indicates the Turing machine reject the character string.

Accept ≠ Reject



A data type that can be moved left or right: it can output or be inputted data(the language consists of the alphabet of ∑) infinitely(write or modify, and space blank is allowed).

Chart 1. The Standard Structure of Turing machine

Why the operation of Turing machine is intelligent? Because its core mechanism fits the definition of intelligence——selecting. The machine behavior of the read-write head of Turing machine is completely determined by δ (transfer function), while δ (transfer function) is absolutely a selection. As shown in Form 2 (which takes Y = f (x) = 2x as an example), all input for the data type is B(blank space), 0 (character) and 1 (character). That means the environmental agent will make a selection under every circumstances, the result of every selection(which indicates character, left-right direction and the next state) will be shown in the Form, like (1, L, q7), and the selected terminal state is the computed result of the function (the written result will be arranged as character strings that dropped vertically). Therefore, the transfer function of Turing machine abstracts the selection of environment. The computed result of Turing machine's transfer function fits the function's computing expectation, which is equal to the realization of the goal (which amounts to humans' intentionality) mentioned by Gregory, Sterrett, Legg and Hutter.

Form 2. The Turing machine's Instruction Set(transfer function δ) of Y = f(x) = 2x

Current state	The writing, movement and state transition when *B* is being scanning.	The writing, movement and state transition when 0 is being scanning.	The writing, movement and state transition when 1 is being scanning.
q_1	*1, L, q_7*	0, *R*, q_1	1, *R*, q_2
q_2	*B, R, q_3*	0, *R*, q_2	1, *R*, q_2
q_3	0, *L*, q_4	0, *R*, q_3	-
q_4	*B, L, q_5*	0, *L*, q_4	-
q_5	-	1, *L*, q_5	0, *L*, q_6
q_6	*B, R, q_1*	0, L, q_6	*1, L, q_6*
q_7	Accept	*B, L, q_7*	-

Why Turing machine is the model of every intelligent processing unit (IPU) of discrete variable and why we say Turing machine is the model of all mechanical intelligence? There are 3 reasons for those questions: 1. Turing machine's behavior—move, stop, read(input) or write(output)—has highly general characteristics; it imitates all the certain behavior(action) patterns of both organisms and machines; 2. The essence of Turing machine is to reach the expected targets by selecting; and its sample space of selection and targets is large enough to cover the information abstraction of organisms and other physical worlds; 3. Turing's model (Turing machine) has mechanical realizability—effectiveness. Therefore, Turing machine becomes the universal intelligent model for the operational mechanism of both organisms and machines. Turing machine, so to speak, is the product of the ideological trend of mathematical mechanization, and then is the expression of the reductive property of intelligence.

3. The Mathematical Expression of Computable Intelligence

As a mechanical computing device, what is the mathematical model of Turing machine's transfer function. In essence, that is the question of the mathematical expression of models of intelligence, which is the question of the expression of the computability of intelligence.

The computability of Turing machine, in fact, is the mechanical depiction of mathematics, which indicates whether it is possible to mechanically depict and find mathematical solutions. On the other hand, the pure mathematical question of what kind of mathematical function computed by mathematical computations that have already been implemented is more abstracted than the depiction of mechanical devices.

Before the birth of Turing machine, the discussion about solving problems by using mathematical functions had been conducting in the fields of philosophy and mathematics, and it began to intervene in the cross field between mechanical computing and mechanical depicting from the field of pure mathematics. That is the discussion about algorithms. The discussion of the essence and implementation of algorithms is an essentially discussion of mathematical mechanization. The essential meaning of "algorithms" is effectiveness, and effectiveness is mechanical, which means it can be achieved through simple(intuitive and operational) steps.

In 1900, David Hilbert put forth a most influential list of 23 unsolved problems at the International Congress of Mathematicians in Paris and predicted that those problems would be solved by the end of the 20th century. Hilbert's 10th problems is " to find an algorithm to determine whether a given polynomial Diophantine equation with integer coefficients has an integer solution", which means whether there is an algorithm that can find an integer solution[13]P66 of the equation: a1x1b1 + a2 x2b2 + ······ + an xnbn = c (1). That problem is the algorithmic problem that can decide whether there is an solution of the equation, and in order to solve that problem, Turing designed Turing machine.

However, what is the mathematical expression for the ubiquitous algorithms? Is there a function that can express all Turing's computability? In fact, recursive function is exactly equivalent to Turing's computability.

Hilbert firstly used the concept of "recurrence" in 1904[14]P51-102. In 1923, Skolem brought forward the idea of recursive function[15,] and he proved the relations (regardless of infinite computation), such as addition, subtraction, multiplication and division, all belong to recursive function. Since 1931, when Godel extended the definition of recursive function[16,17], "universal recursive function"(short for "recursive function") have combined constant function, successor function and projection function (those three functions are called primitive recursive function), as well as functions produced by the compound or recursion of those three functions, together with minimum function into the range of "universal recursive function". According to Godel's definition of "universal recursive function", the later discovered Ackermann function, whose recursive speed is more faster, also belongs to universal recursive function. Those functions mentioned above should be all the numerable discrete variable functions known so far[18].

Alonzo Church had studied functions since 1930s. In April, 1934, Church used "recursive" instead of "definable" in the proposition of his thesis and submitted it to the American Mathematical Society in order to demonstrate that Church's Thesis is an effectively computable function, which is equal to recursive function[19]. In his proposition, Church interpreted "recursive function" as the "universal recursive function"[20] defined by Godel. Stephen C. Kleene explained Turing's thesis (the Church-Turing thesis) as "every number-theoretic function (a1, a2, ... , an) for which there is an algorithm—which is intuitively computable (one sometimes says 'effectively calculable') — is Turing Computerable; that is, there is a Turing machine which computes it ...".[21]

According to the concept of universal recursive function defined by Godel, recursive function (universal recursive function) should include these recursive functions and logical relations as listed bellow(in Form. 3):

Form. 3 The Classification of Recursive Function[22,23]

<table>
<tr><th colspan="6">Recursive function(universal recursive function, general recursive function, GRF, partial recursive function)</th></tr>
<tr><th colspan="4">μ - recursive function</th><th rowspan="3">Ackermann function</th><th rowspan="3">Other recursive functions</th></tr>
<tr><th colspan="3">Primitive recursive function</th><th rowspan="2">Minimum function (μ - operator function)</th></tr>
<tr><th>Constant function</th><th>Successor function</th><th>Projection function</th></tr>
</table>

Therefore, Turing machine, in fact, becomes the implementation model of recursive function. Because the selection mechanism of Turing machine is the intelligent depiction of essential features, Turning Machine and its recursive function of mathematical model become the expression of computable intelligence.

4. The Core Nature of Computable Intelligence

What is the core nature of computable intelligence? Based on the understanding mentioned above, if intelligence can be restored as Turing computing, the essence of the question is: what is the core nature of Turing computing? Moreover, the question is equal to figure out the core nature of recursive function.

The recursive function formed by the recursion of the primitive recursive function f can be found in simultaneity equations (2) (3) [24]:

$$f(x_n, 0) = g(x_n) \qquad (2)$$

$$f(x_n, y+1) = h(x_n, y, f(x_n, y)) \qquad (3)$$

The features of the equations' solving process are listed below:

The computing of the recursive function *f* can be solved by the known functions *g* and *h*;

The variable of *h* is also computed by the unknown numbers—put the computed result of (2) into the third variable of *h* (as is shown in the circuitous arrow);

In the first step of the computing of the unknown number *y*, y is equal to 0, as shown in equation (2); besides, as shown in the two turn-round arrows of (3), *y* could increase progressively and the computing of function *f* after every progressive increasing could be conducted through "substituting back *f* step by step".

Thus it can be seen that the core nature of recursive computing is that: recursion is a resolving computation in space and a divisional computation in time.

The resolving computation is reflected in that *f* is solved through g and h, and the variable of h is solved through *f*; the divisional computation is reflected in that the function of y is increasing progressively and each progressive increasing result will be used in solving the last computing result. That is the implementation of the universal mathematical expression of Turing machine's transfer function.

It is because of the resolving computation in space and the divisional computation in time that recursive computing can conduct the computations on all kinds of discrete variable functions. That means for complicated functions that contains unknown functions or unknown quantities, recursive computing can resolve them into the computations of known functions; for unknown numbers, recursive computing can conduct the computations through gradually approaching the result started with the initial value. It is a computing idea that making complicated computations into simple ones, and just because of that idea, recursive computing can conduct computations on various functions as long as they can be resolved and divided in the process of computing.

5. The Definition of the Relevance between Intelligence and Its Computability

The discussion and evaluation mentioned above demonstrates that the history of ideas on computable intelligence can be expressed by the formulas as below:

Intelligence = Organism intelligence = Machine intelligence = Universal intelligence = Turing machine = The implementation of recursive function = The implementation of universal recursive function

Obviously, that is a historical prospect of the theory of computationalism and strong artificial intelligence. The refutation of the theory mainly comes from the two aspects listed as below.

5.1The Ideas on Non-reductionism

One of the representatives is John Searle. He said, "what kind of fact fits your statement 'I am painful now?' ... If we want to conduct the reduction in the ontology, the essential features of pain will be omitted." [25] Searle proved that AI had non-reductibility by virtue of that viewpoint. But he failed to explain what is omitted between computation(or AI) and "pain". As a matter of fact, some people do view the features of consciousness as intelligence or human beings' advanced intelligence. However, Ludwig Wittgenstein refuted that claim.[26] On the question that "whether stones will feel painful or not", he had made some implicit answers, which meant that machines could have those kinds of feelings. In modern practices, people use physical circuits to imitate the physical state of sympathetic nerves.[27] This paper suggests that if the pain do not exceed the range of physical laws(which means to observe physical laws), it will be physical, which indicates that the pain could be imitated or duplicated by physical quantities; in other words, the pain could be reproduced(although it may be have some discrepancies individually, it do not prevent researchers from reproducing that phenomenon and its essence). Another tendency, which is unacceptable in this paper, is to propose that we should regard all low-level consciousnesses that do not belong to the rational, like emotion, feeling, potential consciousness and subconsciousness, as intelligence. The common sense in the fields of psychology and medical science is that not every consciousness is intelligence. We can divide consciousnesses into intelligence factors and non-intelligence factors. Emotion, feeling, potential consciousness, subconsciousness as well as emotional quotient (EQ), etc. should belong to non-intelligence factors. We can not deny machines' having intelligence just because we believe machines do not own those features at present or in the future. In other words, even though machines are not able to completely conduct the reduction of some non-intelligence factors, such as experience and feelings, their intelligent features are still undeniable.

5.2 The Ideas on Turing's Incomputability

At the beginning of designing Turing machine, incomputable functions and unsolvable problems had already been found. Turing made two examples of the problem of the test of the algorithm of Diophantine equation and the problem of the test of Godel's incompleteness theorems. Up to now, part of the content of Turing's incomputability has been discovered. Although Turing's incomputability has been proved, this paper believes that there is no certain answers for Turing's two examples of questions mentioned above. Therefore, the existence of those problems can not refute Turing's computability.

6. Conclusion

If we admit that intelligence is physical, not binary, we should admit that intelligence can be made artificially or be imitated physically. That idea, after a century's development, has become the idea of strong artificial intelligence. The key point of that idea is that the essence of intelligence is a selective action, which is mechanical, that tends to system objectives. Therefore, intelligence can be depicted and computed by discrete functions, and the superficial features of that computation are recursive functions, which are equal to universal recursive functions. Up to now, the idea of strong artificial intelligence has been proved by many experiments and there is no sufficient reasons and proofs to refute that idea. Although Turing's computability has its own limits, there is no evidence can show that human beings' intelligent actions surpass Turing's computation.

Works Cited

A. M. Turing Computing Machinery and Intelligence [C]. Mechanical Intelligence. Collected Works of A. M. Turing. North-Holland, 1992.

A. M. Turing Intelligent Machinery. Mechanical Intelligence [M]. Collected Works of A. M. Turing. North-Holland, 1992.

Alan Turing. On Computable Numbers, with an application to the Entscheidungsproblem, Proceedings of the London Mathematical Society, 42(1936 -- 1937): 230, 231, 262.

Alonzo Church. An Unsolvable Problem of Elementary Number Theory [J]. American Journal of Mathematics, 1936, 58, (2).

Edna E. Reiter, Clayton Matthew Johnson: Limits of Computation, An Introduction to the Undicidable and Interctable. CRC Press, 2012.

Kurt Godel. On Formally Undecidable Propositions of Principia Mathematica and Related System I. From Frege to Godel, Harvard University Press, pp. 592 - 617.

Pentti O Haikonen. Consciousness and Robot Sentience. (One of Serials on Machine Consciousness), World Scientific Publishing Co. Pte. Ltd. 2012.

Rechard Gregory. Seeing intelligence /Jean Khalfa edited. What is Intelligence? [M]. The Press Syndicate of the University of Cambridge, 1994.

Robert I. Soare. Computability and Recursion, Bulletin of Symbolic Logic /Volume 2 /Issue 03 /September, 1996.

Robin Gandy. The Confluence of Ideas in 1936. The Universal Turing Machine/A Half-Century Survey, Springer - verlag [M]. Wien New York, 1994, 1995.

Shane Legg, Marcus Hutter. Universal Intelligence: A Definition of Machine Intelligence [J]. Mind & Machines, 2007, (17).

Stephen C. Kleene. Turing's Analysis of Computability, and Major Applications of It, The Universal Turing Machine/A Half - Century Survey, Springer - verlag, Wien New York, 1994, 1995:15 - 49.

Stuart Russell, Peter Norvig, 人工智能——一种现代方法 [M]. 第二版. 北京: 人民邮电出版社, 2009.

Susan G Sterrett. Too many instincts: contrasting philosophical views on intelligence in human and non-human [J]. Journal of Experimental & Theoretical Artificial Intelligence, 2002, 14(1).

Thoralf Skolem. The foundation of elementary arithmetic established by means of the recursion mode of thought, without the use of apparent variables ranging over infinite domains. /From Frege to Godel // A Source Book in Mathematical Logic, 1879~1931. Havard University Press, 1977: 302 - 333.

哥德尔. 论《数学原理》及其相关系统的形式不可判定命题(I) 张寅生译. 张寅生. 证明方法与理论[M]. 北京: 国防工业出版社, 2015.

塞尔. 心灵的再发现 [M]. 北京: 中国人民大学出版社, 2005.

维特根斯坦. 哲学研究 [M]. 北京: 商务印书馆, 1994.

希尔伯特. 数学问题 [M]. 李文林, 袁向东编译. 大连: 大连理工大学出版社,2009.

张寅生. 计算理论解析 [M]. 北京: 清华大学出版社,国防工业出版社,2016.