The Legacy of A.M. Turing

Edited by
Evandro Agazzi

E

Epistemologia

FrancoAngeli

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La collana intende venire incontro a quell'esigenza, ormai generalizzata, di conoscenza epistemologica che si riscontra a livello di cultura medio-alta e che corrisponde, in senso lato, alla diffusa aspirazione a prender coscienza critica della complessa varietà della nostra civiltà scientifico-tecnologica. Aspirazione che si accompagna, altresì, al desiderio di venire in chiaro circa lo statuto epistemologico di molte discipline le quali solo di recente hanno rivendicato l'impegnativa qualificazione di «scienza», pur riguardando ambiti di ricerca non inclusi nell'alveo delle discipline scientifiche tradizionali.
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Verranno quindi pubblicati, sia in traduzione che in opere originali, alcuni testi base di carattere istituzionale relativi all'epistemologia generale e alle diverse branche della filosofia della scienza. Per altro verso, verrà dato uno spazio più cospicuo del solito all'epistemologia delle scienze «umane», alla filosofia della logica, alle tematiche etiche che di recente si sono aperte nei riguardi della scienza. Pur senza rinunciare ad opere di carattere tecnico, l'accento generale verrà posto piuttosto su quei tipi di trattazione epistemologica nei quali è più presente un taglio specificamente filosofico.
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The Legacy of A.M. Turing

(Papers presented at the Conference of the International Academy of Philosophy of Science - Urbino, 25-27 September 2012)

Edited by
Evandro Agazzi

Evandro Agazzi – Marco Buzzoni – Claudio Calosi –
Vincenzo Fano – Jean Faye – Luciano Floridi – Fabio Giglietto –
Pierluigi Graziani – Lella Mazzoli – Jean Guy Meunier –
Fabio Minazzi – Massimo Negrotti – Roland Omnès –
Jean Petitot – Gino Tarozzi

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Introduction: Alan Turing, a Polyhedric Figure

Evandro Agazzi

The broad spectrum of the celebrations devoted worldwide to the first centennial anniversary of the birth of A. Turing (1912) may produce, at first, a certain surprise. Not only because such celebrations usually concern great figures of literature, music, fine arts rather than scientists, but also because, among the sciences, the capacity to attract the attention of the general public seems to be the privilege of the natural sciences whose "discoveries" and technological applications have a more tangible impact on people's life, and on the course of human civilization. In the case of Turing, on the contrary, we have to do with a mathematician, and moreover, with someone whose scientific activity could cover a span of less than two decades and, consequently, could also produce only a modest quantity of results. Yet we are aware that this wide homage is well deserved, and that the recognition of the importance of Turing's work has rightly increased, instead of decreasing, with the passing of time. Therefore it is worthwhile to reflect on some reasons for this fact, and the first that comes to mind is that Turing's work provides a powerful confirmation of an easily neglected – but actually fundamental – role that mathematics has played in the development of human thought and particularly of science.

Mathematics as a tool for the analysis of concepts

The most outstanding figures in the history of modern science have been characterized by a significant intellectual "openness" that in a certain sense counterbalanced the increasing tendency toward specialization that was becoming dominant in the field of scientific "research", whose output had to be evaluated on the ground of precise new "results" acquired. If we take the pervasive use of mathematical tools as the most salient feature of modern science, we can easily ascertain, however, that mathematics, far from being the realm of pure abstract speculations, has served for the explicit and exact determination of many *general concepts*. The meaning of these concepts was rooted in everyday language (and was affected by the vagueness that they must have in order to be of use in the flexible applications of this language), but when one such concept had to be used in the language of a certain scientific discipline, its meaning had to be determined in such a way as to be at the same time *general and specific* for the said discipline. In this enterprise mathematics did not play its traditionally recognized role of an instrument for *calculating* magnitudes, but rather the role of a tool for the *analysis* of the meaning of certain basic concepts.

The impacts outside science

One could say that such a determination is rather the task of logic, but this remark is rather empty if we do not indicate *in what context* we consider the concept whose meaning we intend to analyze, make explicit and precise. If this context is that of "common language" we were quite naïve if we believed that this is the "general" context, since everyday language is just a "particular" context itself. Therefore, when Galileo (for reasons we do not want to consider here) proposed as the task of natural science that of investigating only certain privileged properties of physical bodies, that is, the mathematizable properties, and Newton fully shared this option, it was already implicit that, *within this context*, mathematics had to serve also for the exact determination of the fundamental concepts of natural science. This actually happened, but then a tension surfaced between the "specific generality" of the mathematized concepts of natural science and the (alleged) "full generality" of the corresponding commonsense concepts, a tension that almost inevitably involved philosophy of nature, metaphysics, and even theology, and it is not accidental that Galileo and Newton (just to mention the two founding fathers of modern science) were seriously interested in issues belonging to these fields and – at least in the case of Galileo – had to suffer painful consequences of such an interplay. This, however, was not surprising, if one simply considers the deep differences introduced by modern science with regard to very general concepts of everyday worldview. For example, rest and motion are normally considered as opposite states intrinsically attached to a physical body, and it belongs to the common meaning of rest to consider it as the "natural state" of a body, while motion is understood as a departure from rest that requires a cause for its explanation. Ancient philosophy of nature accepted this intuitive view, as well as the similar intuitive view that "upwards" and "downwards" are absolute spatial regions, and in such a way the cause of the natural motion of physical bodies was indicated in the tendency of every element to attain its "natural site", upwards or downwards. In modern natural science motion does not require a cause, but only change of motion does, while rest and motion are not intrinsic properties of a body, but only relations with respect to a reference frame. The allegedly more general commonsense intuitive notions are simply the consequence of having adopted as general the very particular frame of reference constituted by the surface of the Earth. Thanks to these novelties, motion had acquired the metaphysical connotations of a "substance", which remains fundamentally the same under the different transformations to which it can be submitted. Also mass has this characteristic, and this is reflected in the two conservation principles of classical mechanics, the conservation of mass and the conservation of motion. But how had the conservation of motion to be understood? On this point a century-long dispute between Cartesian and Leibnitian scholars took place and was also taken up by Kant. The Cartesians measured this magnitude as mv, and the Leibnitians as mv^2, while the whole controversy was qualified as the dispute on the "living forces". Similar disputes regarded also other fundamental principles of Newtonian mechanics, such as the principle of least action, and spanned from mathematics, to physics, to natural philosophy, to metaphysics and theology.

Feedback-loops within the sciences

If we restrict our attention to the domain of the sciences, we can note that several mathematical tools were created and developed in order to analyze concepts and solve logical problems occurring within certain specific sciences. For example, the geometrical notion of the direction of a curve at a given point was identified with the direction of the tangent to the curve at this point, but the problem of giving an objective measure of the incline of the curve at that point, and in general at all its different points, could be solved only with the creation of differential calculus, which is a part of infinitesimal analysis, and the same tool offered the way for defining the physical (mechanical) concept of instant velocity of a moving body. Similarly, the other branch of infinitesimal analysis (that is, the integral calculus) provided the means for calculating areas and volumes of the strangest geometrical figure as well as to express the mechanical properties of solid bodies, while differential equations of several sorts were used for the formulation of physical laws and principles.

Yet at the beginning of the 19th century the need of making precise the fundamental concepts and tools of infinitesimal calculus imposed itself to the working mathematicians, owing to the paradoxical situations that could follow from the uncontrolled use of the very notions of "infinitesimal" and "infinite". In this case the work of refinement and precision had to be done within mathematics itself, and was accomplished by the rigorous definition of the concept of limit and its application, for instance, to the definition of the sum of an infinite series, of the derivative, the integral and the continuity of a function. This amounted to a liberation of analysis from the geometric and mechanical intuitions that had constituted its original background, but this independence also entailed the possibility of certain discrepancies with regard to those intuitions (for instance, the existence of functions that are continuous but nowhere derivable entailed the anti-intuitive consequence that the curve being the graphic representation of such a function was continuous, and yet with no tangent at any point). In addition, the careful restriction to "potential infinity", that was the salient feature of the concept of limit, turned out to be an obstacle to the acceptance of Cantor's set theory in which "actual infinity" is the conceptual foundation for the construction of transfinite arithmetic.

We do not want to go on with similar examples. The few hinted at here are sufficient to show how the exact determination of the meaning of several seemingly general, intuitive and elementary concepts required the elaboration of sophisticated mathematical tools, from which new branches of mathematics could start. Even such basic notions as that of number and of proof were submitted, in the last decades of the 19th century, to a complex work of definitions and constructions in which many of the greatest mathematicians and logicians were deeply involved, such as Dedekind, Weierstrass, Cantor, Frege and Peano, to mention only few of them.

Many-sided scientists

At first sight this rich display of developments was an internal affair of mathematics, occasionally stimulated by the progress of physics, but the fact of concerning several very "general" concepts and principles inevitably had effects not only on the philosophy of certain particular sciences (especially mathematics and physics), but also on general epistemology, logic, ontology, metaphysics, as is patent from the fascinating history of the non-Euclidean geometries and the disputes on the "foundations of mathematics", not less than in the case of the similar debates on the "foundations of physics" that took place in the last decades of the 19th and the first decades of the 20th century. This variety of impacts, implications, connections is also reflected in the multifaceted personality of certain outstanding scientists. Some of them significantly contributed to different sciences (for example, Helmholtz, who produced important contributions in physiology, geometry, electromagnetism, theoretical physics, and expressed interesting ideas in the domain of epistemology and of scientific methodology). Others, such as Poincaré and Hilbert, not only did eminent work in various domains of pure mathematics and mathematical physics, but were reference figures in the philosophy of science, in logic and philosophy of logic, and had a conspicuous influence on certain philosophical schools of the 20th century.

The case of Turing

This rather extended preamble should make easier the appreciation of the reasons that rank Alan Turing among the most outstanding scientists of the 20th century, despite the not great amount of his published papers. The reason is that in some of these papers he proposed an original mathematical analysis and characterization of general concepts and derived from this analysis certain abstract and concrete consequences that opened new vistas in several fields of research and also started the development of the most typical technologies of our time. Moreover, these new views also had a strong resonance in philosophy and outlined very interesting approaches in biology and quantum physics. In short, Turing was a paradigmatic example of how mathematics can be an instrument of intellectual clarification and open new pathways in different sciences. At the same time, though he never presented himself as a philosopher, his 1950 article, *Computing Machinery and Intelligence* (the only paper he published in a philosophical journal, that is, in *Mind*) is certainly one of the most quoted titles in the modern philosophical literature and, in particular, in the philosophy of mind. This original philosophical contribution (that introduced a new approach in the analysis of the classical mind-body problem), however, is not the result of pure speculation, but the development of the definition of the mathematical concept of computability that he had himself offered in his famous first paper of 1936, *On computable numbers*. Owing to his "operational" approach to concepts, and to his ability to find technological implementations of abstract models, his work can be considered as the foundation of computer science and of the artificial intelligence program. This amazing capability of establishing unexpected correlations between apparently distant domains is the consequence of his having grasped the core of certain very general concepts and then followed their role within different fields.

The concept of computation

This is clear if we consider the fact that his sudden and impressive debut, when he was only 24 years old and was starting his postgraduate work in mathematics, concerned mathematical logic, a domain where he was completely unknown. Here his effort was that of making clear and totally explicit one of the most basic concepts of mathematics, that of computation that, at least starting with the famous *calculemus* of Leibniz, had come to denote a distinctive operation of mathematics and logic (indeed the operation that allows to consider logic, from a certain point of view, as a branch of applied mathematics). The already quoted paper *On Computable Numbers…* that was Turing's first (and perhaps greatest) achievement, gave a satisfactory definition of computation and established an absolute limitation of what computation can attain. In such a way the general framework of computer science was traced and the same Turing was going to move further significant steps in this new field when (after the second World War) he engaged himself in the project for the realization of the first electronic computer.

The fact of having uncovered the theoretical limitations of computation pushed Turing to study the problem of comparing the power of computation and the power of the human brain. He advocated the idea that the computer (if properly programmed) could rival the brain, and this can be considered the starting moment of the "Artificial Intelligence" program destined to know enormous developments in the coming decades. In fact the already mentioned "philosophical" paper, *Computing Machinery and Intelligence* represents a consistent set of indications for the program of Artificial Intelligence and, at the same time, opens the way to several philosophical discussions regarding the relations between the brain and the mind, the proper definition of intelligence, and many other issues that are still warmly debated today.

This was not, however, the last interest of Turing: two years after the publication of his article in *Mind,* appeared a paper concerning an entirely new field, that of biological morphogenesis, for which Turing was creating a fresh mathematical theory (*The Chemical Basis of Morphogenesis*, 1952). His research activity was not interrupted even by the sad events of the process in which he was condemned for homosexuality (and he even advanced new ideas for fundamental physics), but his tragic death in 1954 stopped such a creative life that in the time span of 16 years (of which 6 were absorbed by his activity as cryptographer for the British communication war) has produced so many pioneering ideas and knowledge achievements.

The Turing machine

For the (cultivated) general public the name of Turing is strictly associated with the idea of the "machine" that is named precisely after him, and this association seems a little surprising in the case of a mathematician. The surprise, however, is unjustified since the *abstract* concept of a machine turned out to be the most suitable means for making clear and precise two concepts that were at the core of one of the most famous problems of mathematical logic at that time, the "decision problem" whose solution was essential for the success of Hilbert's formalistic program in the foundations of mathematics. The problem can be formulated as follows: "Does it exist a method by which it is possible, given any mathematical proposition, to decide whether or not it is provable"? The idea lying behind the Leibnitzian *calculemus* was that the creation of a suitable symbolic "calculus" for the logical deductions could actually offer such a method, so that two philosophers maintaining opposite claims could simply find out a set of premises on which they agreed and then "seat at the abacus" and calculate without engaging in additional disputes.

At the end of the calculation, it would automatically appear who was right and who was wrong. Hilbert's decision problem was only a refinement of this idea and, if the "decision problem" had a positive solution, it would amount to the thesis that whatever (precisely formulated) mathematical problem has a solution, because the "decision method" would prove or disprove, after a finite number of steps, the proposition expressing the proposed solution of this problem.

The tacit prerequisite of this discourse is attaining an unobjectionable, correct and general definition of what has to be a "definite method", as well as an "effective procedure" capable of producing the decision in question. In the formalistic literature of that time the requirement of total explicitness and purely automatic application of rules without the intervention of meaning and intuitions, had often been expressed by calling purely "mechanical" the performance of the logical operations. One could say that Turing took literally, and not just metaphorically, this idea, and tried to imagine a *machine* that could actually concretize the method or procedure at issue by performing a succession of simple atomic operations. This machine is obviously an ideal *model* inspired by the way of functioning of a teleprinter with only a couple of enlargements (the paper tape can move in both directions, and the "head" can read, erase and print new symbols, instead of just reading and punching permanent holes). The important fact, however, is that this machine is "theoretical" in the sense that it would not make sense to concretely build it, but all its components and operations are such that *could* be really implemented. The great advantage of this model was that the concept of "definite method" was clearly made explicit by the indication of simple operations that can really by "effected".

The machine, the brain and the mind

We are not interested here in talking on the more technical issues treated in this seminal paper, as well as on the possibility shown there to give a precise definition of what is *computable* (anythig that is computable can in fact be computed by a "universal" Turing machine), nor to see how the model of this machine could be applied to answer the question of the decision problem. We want rather to point out that Turing's goal was that of representing by his machine the general mechanical process carried out by *human beings*. His final idea, emerging after 1945, was that computable operations are sufficient to embrace the totality of mental functions performed by the brain. In this way he opened the way to the program of artificial intelligence, in which he also brought interesting contributions of a technical kind. What is more significant, however, is that he went beyond the purely technical problem, by addressing also the philosophical problem of the possibility of distinguishing human intelligence from machine intelligence. In his 1950 paper he presents his famous “test” that still constitutes a matter of debate among the specialists of artificial intelligence and philosophy of mind. We will not enter this discussion, but simply note that this connection with philosophy is again a confirmation of the polyhedric personality of Alan Turing and of his exceptional stature: indeed all the greatest scientists of our time have been sensitive to philosophy and have offered with their work abundant stuff to philosophical reflection, precisely as Alan Turing has done.

The contents of the present book

The International Academy of Philosophy of Science devoted its annual conference (that took place at the University of Urbino on 25-28 September 2012) to the theme *The Legacy of Alan M. Turing*, and the present book contains the revised version of the majority of the invited papers presented at that conference. They are divided into three thematic parts.

Part One (*Human Intelligence and Machine Intelligence)* contains papers concerning the possibility, explicitly advocated by Turing, of equating the performance of the brain in securing human intellectual activities with the performance of a suitably programmed computer, that is, the central philosophical issue of Artificial Intelligence. The paper by Marco Buzzoni, *Is Frankestein's creature a machine or artificially created human life? Intentionality between Searl and Turing,* brings to the fore some elements of truth both in the Turing Test and in Searle's Chinese Room thought experiment, and proposes to distinguish between two different senses of intentionality: a reflexive-transcendental sense and a positive-empirical one. In the first sense, intentionality is intimately connected with thought experimentation and denotes the capacity of the mind to assume as merely possible any actually given reality. Pace Searle, we have no idea as to how intentionality, in this transcendental sense, may be implemented not only in a Turing machine, but also in any robot, brain or living being produced by our scientific and technical intelligence. This is why, in case a machine passed the Turing Test, neither science nor philosophy can find an answer to the question whether the artificial life so produced, or the creature in Frankenstein's novel, is a human being or a dangerous machine. However, such a choice could and should be made by assuming the supreme value of the human person and by applying the principle of precaution.

While Buzzoni's paper is deepening a still debated “philosophical” question concerning the original classical approach to artificial intelligence, the paper by Claudio Calosi and Gino Tarozzi, *Is the mind a quantum computer?* provides a critical assessment of Quantum Artificial Intelligence, that is, roughly speaking, the view that the human mind can be effectively simulated by a quantum computer. In particular the paper raises several independent problems for such a view, namely a supervenience problem, a quantum measurement problem, a decoherence problem and an indiscernibility problem. As is patent, the critical perspective, in this case, is specifically centered on physical (more precisely quantum theoretical) difficulties rather than on philosophical questions.

It is well known that the debates on the possibility of "mechanizing" human reasoning have been widely influenced by results obtained in mathematical logic and this, after all, has direct links with the first seminal paper by Turing (1936). In particular, Gödel incompleteness theorem has been often at the center of such debates. The paper by Vincenzo Fano and Pierluigi Graziani, *Mechanical intelligence and Gödelian arguments* offers a detail critical survey of such debates. An analytical history of Lucas-Penrose Argument is presented in this paper, starting with 1951 Gödel's Gibbs Lecture, in which the great logician showed how from a reasonable application of his incompleteness theorems derives a sort of dilemma concerning Mechanism: either our intellectual ability is not represented by a Turing Machine, or we will never know with mathematical certainty which Turing machine represents our intelligence. This kind of arguments is very different from the Lucas-Penrose ones; since the latters attempt to prove the stronger thesis that our intelligence is hyper-computable. The present paper shows that Chihara and Benacerraf – independently from Gödel – investigated the topic, proving the substantial correctness of the argument. Nonetheless the weak point of this kind of Gödelian reasoning is the sloppy definition: "all true theorems of arithmetic a group of mathematicians prove with indefinite time available". Many philosophers of mathematics consider this notion too vague for any good argumentation.

Precisely because Gödel himself has explicitly recognized on several occasions that Turing's Machine is the most appropriate representation of the very concept of formal system, and had seen in Turing's results a faithful correspondence with his own results on undecidability and related issues, the exploration of the relationships between Turing's logical-philosophical views and the more general problems evocated in this connection within the philosophy of logic and mathematics appears as a very reasonable challenge. This thematic is addressed in the paper by Fabio Minazzi, *Turing and the epistemological value of the general concept of formal system* in which an historical reconstruction is offered of the process that led to the dominance of the formalistic outlook in the philosophy of mathematics, and of the crisis of this paradigm derived from Gödel's and Turing's results. A critical discussion follows concerning the reasons and limitations of formalism, including reference to recent research in this domain.

Part Two (*Discussions on Turing Test*) opens with a paper by Jan Faye, *The Turing test and consciousness: a proposal*, that takes up again, but under a different light, the issue discussed in Buzzoni's paper: Turing argued that in case we could not decide, on the basis of the linguistic responses given to our questions, whether it was a man or a machine (a computer) that gave them, we should not hesitate to ascribe intelligence to a computer. This argument has most famously been criticized by John Searle and his conclusion is on the right track. However, Faye also believes that Searle cannot give an account of consciousness in terms of biological selection and adaptation because he associates consciousness with human language. In the end the paper offers a suggestion according to which qualia and consciousness can be considered as two sides of the same coin, and be understood in relation to the brain's processing capacity. Qualia are what is here called "bundled information" and consciousness is the "reader" of this information.

The Turing Test is taken as an opportunity for the development of a much broader discourse regarding the intrinsic nature of the artificial in the paper by Massimo Negrotti, *The Turing test and the technology of the artificial: theoretical and methodological issues.* The human ambition – says the paper – to reproduce natural objects and processes, man himself included, has a long history, and ranges from pure dreams to actual design. The concept of "naturoid" can be useful for referring to man's reproductions of natural phenomena and to the general rules that govern this effort in any technological field. This paper tries to show that a naturoid is always the result of a reduction of the complexity of a natural object, due to an unavoidable multiple selection strategy and to constraints outlined *in nuce* in the Turing Test.

If a significant broadening of horizon characterizes Negrotti's paper in relation with Turing Test, an even broader perspective, taking in a way inspiration in the whole of Turing's work, is presented in the paper by Luciano Floridi, *Turing's three philosophical lessons and the Philosophy of Information.* This paper outlines three main philosophical lessons that we may learn from Turing's work, and how they lead to a new philosophy of information. After a brief introduction, Turing's work is discussed on the method of levels of abstraction (LoA), and his insistence that questions could be meaningfully asked only by specifying the correct LoA. Then a second lesson is considered, about the sort of philosophical questions that seems to be most pressing today. Finally, the paper focusses on the third lesson, concerning the new philosophical anthropology that owes so much to Turing's work. It is then shown how the lessons learnt are taken up by the philosophy of information, that can be considered, in such a way, as a continuation of Turing's work.

Part Three (*Complexity and Models of Computation)* includes papers that exemplify the fruitful applicability of some of Turing's most abstract concepts as powerful tools for the organization of various fields concerned with complex realities. The paper by Jean-Guy Meunier, *Computers as cognitive models of computors and vice versa* recognizes that, according to the dominant formal model in cognitive sciences, cognitive operations are computational and the brain mechanisms that enact them are seen as analogous to those of a computer. Such a model has been criticized from different perspectives: for some it lacks semantics, while for others it is a static or inadequate model, even a "failed program". But many of these criticisms are based on an often oversimplified conception of Turing's original computing machine, whose sole objective was to imitate "computors", i.e. humans "calculating with pencil and paper". Since his first presentation, Turing himself as well as later scholars have contributed to the refining of the computational model behind the functioning of this machine. However, many of these highly technical modifications were left out in the cognitive appropriation of this model. By revisiting Turing's original machine as well as its theoretical developments, the present paper aims to shed new light on the computational issues related to cognitive models.

The potentialities of Turing Machine for modeling complex realities is not limited to the already wide domain of the interpretation of human intelligence and the technological applications in artificial intelligence, but reveal important applications also in seemingly distant domains. This fact is discussed in the paper by Lella Mazzoli and Fabio Giglietto, *Social systems: from simulation to observation*. The cognition-computing short circuit, one of the most important legacies of Alan Turing's work, is still affecting both neuroscience and computer science today. Starting from the proposals formulated by Turing, this paper underlines the seldom studied impact his ideas have had on the study of society. Social systems theories, on the one hand, and agent-based simulations on the other, have once more pinpointed the traditional sociological dualism between macro- and micro-sociology. However, the advent of 'Big Data' has paved the way to new techniques of investigation based on the study of new types of data, such as conversations taking place on popular web sites like Twitter and Facebook. Thanks to these techniques, we can go beyond simulation and observe the operation within the social "black box" in the same way that neuronal functional magnetic resonance imaging (fMRI) does as regards the brain. The paper discusses the potential as well as the limitations of these new methods of sociological investigation and their spill over effects on the theoretical development of the discipline.

The last two papers are related with the new intellectual and scientific interests that characterized the last two years of Turing's life, that is, biology and physics. The paper by Jean Petitot, *Complexity and self-organization in Turing*, is a detailed and thorough study of Turing's seminal paper on "The chemical basis of morphogenesis" (1952), that had a deep impact on mathematical modeling in biology. In this pioneering work, he introduced the celebrated concept of a reaction-diffusion partial differential equation to explain how morphological patterns can be induced by morphogens "reacting together and diffusing through a tissue". The key problem he tackled was to understand how living systems "convert chemical information into a geometrical form".The paper analyzes in a detailed way Turing's article and explains why he represented such a breakthrough for mathematical modeling in biology.

We know that Turing, in the last stage of his life, was also interested in foundational issues of quantum mechanics; more precisely, h e considered the problem, hitherto avoided, of setting computability in the context of quantum-mechanical physics. His ideas and even his proposals in this endeavor remained at an incomplete stage of elaboration, so that a convenient way not to overlook this aspect of his scientific interests may be simply that of presenting the discussion of the possibility of using quantum physics as a tool for interpreting the phenomena of the universe at a very large scale. This is done in the paper by Roland Omnès, *A quantum approach to the uniqueness of Reality* which is a review of some research in measurement theory. The main new result is a derivation of local properties in the growth of entanglement between a measuring quantum system B and a measured one A, implying particularly the existence of collective waves carrying the A-B entanglement. Other waves, to be called here "predecoherent waves", carry in a similar way the entanglement of B with an environment. A link with measurement theory is proposed then as a conjecture relying on interactions between the two kinds of waves. Fluctuations in the probabilities of different measurement channels would be the result and would lead ultimately to collapse (according to earlier works by Nelson and Pearle). Born's probability rule results from such a mechanism but the necessity of some randomness in the environment brings out questions for its origin with an attractive possibility in strong algorithmic complexity for the wave functions of a large system.

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Agazzi Evandro – President, International Academy
of Philosophy of Science – evandro.agazzi@gmail.com

Part One: Human Intelligence and Machine Intelligence