A Note on Turing's Three Pioneering Initiatives and on Their Interplays

Jozef Kelemen
Silesian University, Institute of Computer Science, and IT4I Institute, Opava, Czech Republic
kelemen@fpf.slu.cz

Abstract

The purpose of this article is to remind three fundamental contributions by A. M. Turing to three important fields of contemporary science and engineering (theory of computation, artificial intelligence, and biocomputing), and to emphasize the connections between them. The article reminds and formulates resp., also three hypotheses related to the three initiatives and discuss in short their mutual interrelatedness.

1 Introduction

The purpose of this article is to remind three fundamental contributions made by A. M. Turing to three important fields of contemporary science and engineering – to the theory of computation, to the field of artificial intelligence, and to first approaches to set up formal models of the biological reality. All these contributions are vivid up to now in science. However because of the listed fields are mutually relatively distant, the interplays between the contributions made by Turing to them remain often out of discussions. As its central goal this article tries to make these connections more distinct.

The first Turing's fundamental contribution is the proposal of the first abstract formal model of a computing machine, called the a-machine in Turing's original article (Turing, 1936), and renamed later by Alonzo Church who has also inspired in his research, similarly as Turing, by the so called Entscheidungsproblem, and who played an important role also in introducing the name for the generally accepted *Turing machine* of the present times.

The second fundamental contribution is the Turing's proposal to use the so called imitation game as a base for testing the level of intelligence of the computers through comparison it with the human level intelligence (Turing, 1950) known in the literature on Artificial Intelligence of our times as the *Turing test*.

The third Turing's initiatives we will deal with it in this article is an attempt to construct a precise mathematical model of the biochemical process of *morphogenesis* (Turing, 1952) treated as an important problem up to now.

We will try to show that there is possible to find some perhaps interesting interplay between the three above mentioned Turing's initiatives, and will give some arguments for supporting that proposition. We remind also three hypotheses related to the three initiatives, and discuss in short their mutual interrelatedness.

2 The Machine and Turing's 1st Hypothesis

As it was mentioned above, the machinery called now as the Turing machine and forming the headstone of the present days theory of computation, and in certain sense of the all theoretical computer science has been introduced in (Turing, 1936) under the name *a-machine* (staying for the *abstract machine*) and particularized in the corrections of the previously mentioned publication in (Turing, 1937). The original definition of the a-machine is rather different form the present days definitions, but its basic idea reminds unchanged. This actual definition of the Turing machine can be founded practically in all of the present days textbook or monographs related to theory of computation. The basic idea is in an acceptable form but sketched relatively informally accessible also in the Wikipedia from where we recall the definition of the Turing machine[*]:

"A Turing machine consists of:

A *tape* which is divided into cells, one next to the other. Each cell contains a symbol from some finite alphabet. The alphabet contains a special *blank* symbol (here written as 'B') and one or more other symbols. The tape is assumed to be arbitrarily extendable to the left and to the right, i.e., the Turing machine is always supplied with as much tape as it needs for its computation. Cells that have not been written to before are assumed to be filled with the blank symbol. In some models the tape has a left end marked with a special symbol; the tape extends or is indefinitely extensible to the right.

A *head* that can read and write symbols on the tape, and move the tape left and right one (and only one) cell at a time.

A finite *table* $q_i a_j \rightarrow q_{i1} a_{j1} d_k$, but sometimes 4-tuples) that, given the *state*(q_i) the machine is currently in *and* the *symbol*(a_j) it is reading on the tape (symbol currently under the head) tells the machine to do the following in sequence (for the 5-tuple models):

Either erase or write a symbol (instead of a_j, write a_{j1}), *and then*

Move the head (which is described by d_k and can have values: 'L' for one step left *or* 'R' for one step right *or* 'N' for staying in the same place), *and then*

Assume the same or a *new state* as prescribed (go to state q_{i1}).

In the 4-tuple models, erase or write a symbol (a_{j1}) and move the head left or right (d_k) are specified as separate instructions. Specifically, the table tells the machine to (ia) erase or write a symbol *or* (ib) move the head left or right, *and then* (ii) assume the same or a new state as prescribed, but not both actions (ia) and (ib) in the same instruction. In some models, if there is no entry in the table for the current combination of symbol and state then the machine will halt; other models require all entries to be filled.

A *state register* that stores the state of the Turing machine, one of finitely many. There is one special *start state* with which the state register is initialized. These states, writes Turing, replace the "state of mind" a person performing computations would ordinarily be in.

Note that every part of the machine—its state and symbol-collections—and its actions—printing, erasing and tape motion—is *finite*, *discrete* and *distinguishable*; it is the potentially unlimited amount of tape that gives it an unbounded amount of storage space."

Let us mention that the original definition of the a/machine has been invented in order to make mathematically as precise as possible the notion of computability, esp. in connection with the computability of real numbers, and making possible to answer the question on decidability whether all of the real numbers are computable in certain constructive way as results of some algorithm or not. The Turing's effort to define mathematically precisely the meaning of the algorithm leaded him top

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[*] See http://en.wikipedia.org/wiki/Turing_machine (January 22, 2012). For a more precise and slightly understandable definition see e.g. (Singh, 2009) or the old but gold (Hopcroft, Ullman, 1969).

the concept of the abstract computing machine. The Turing’s own explanation concerning that from the early beginning of (Turing, 1936) is the following:

„The ‘computable’ numbers may be described briefly as the real numbers whose expressions as a decimal are calculable by finite means. Although the subject of this paper is ostensibly the computable *numbers*, it is almost equally easy to define and investigate computable functions of an integral variable or a real or computable variable, computable predicates, and so forth. The fundamental problems involved are, however, the same in each case, and I have chosen the computable numbers for explicit treatment as involving the least cumbrous technique. I hope shortly to give an account of the relations of the computable numbers, functions, and so forth to one another. This will include a development of the theory of functions of a real variable expressed in terms of computable numbers. According to my definition, a number is computable if its decimal can be written down by a machine.“

In (Turing, 1936) a very important statement is proved, too: It is possible to invent (in a constructive way) a single a-machine which can be used to compute any computable numbers (more generally, any sequence of symbols). If this machine, say *I*, is supplied with a tape on the beginning of which is written the so called standard description of some computing machine, say *M*, then the machine *I* will compute the same sequence as *M*, outlined Turing the idea in (Turing, 1936).

However from our perspective, and with respect of the next section contents will has a key importance the observations, made in (Turing, 1936) concerning the generalization of the meaning of computability of number to other mathematical objects, too. Although his subject is ostensibly the computable numbers, it is, citing from (Turing, 1936) “… almost equally easy to define and investigate computable functions of an integral variables or a real or computable variable, computable predicates, and so forth.” In this way the approach is general in the sense that it makes possible to divide all mathematically definable functions into two classes with respect their computability by appropriate Turing machines or, more generally, by the reminded above universal Turing machine.

Shortly after the proposal of the formal model of the universal digital computer – the Turing machine – Alonzo Church who was deeply interested in the theory of computability, too, formulated a hypothesis called today as the *Church-Turing hypothesis* or simply the *Turing hypothesis*. In the core of it stays the question ‘Whether or not are all imaginable computations transformable into the form of computations executable by Turing machines?’ The hypothesized answer is: “Whatever can be calculated by a machine (working on finite data in accordance with a finite program of instructions) is Turing-machine-computable”. One among the informal definitions of the thesis has been formulated personally by Turing: “The idea behind digital computers may be explained by saying that these machines are intended to carry out any operations which could be done by a human computer” (Turing, 1950)[†].

3 The Turing Test and the 2nd Hypothesis

„I propose to consider the question, 'Can machines think?' This should begin with definitions of the meaning of the terms 'machine 'and 'think'. The definitions might be framed so as to reflect so far as possible the normal use of the words, but this attitude is dangerous. If the meaning of the words 'machine' and 'think 'are to be found by examining how they are commonly used it is difficult to escape the conclusion that the meaning and the answer to the question, 'Can machines think?' is to be sought in a statistical survey such as a Gallup poll. But this is absurd. Instead of attempting such a definition I shall replace the question by another, which is closely related to it and is expressed in relatively unambiguous words“.

[†] More about the thesis see e.g. in http://plato.stanford.edu/entries/church-turing/.

This is the first paragraph of Turing’s fundamental paper originated after his participation at the Manchester University discussion on the mind and computing machines of the philosophy seminar chaired by Dorothy Emmet in October 27, 1949. Turing has been dissatisfied by his own argumentation against the arguments of colleagues like Michael Polanyi, neurophysiologist J. Z. Young, and mathematician Max H. A. Newman, for instance. Turing early after the discussion started to write an article devoted to the topic and published it as (Turing, 1951). The question ‘Can machines think’ he replaced by the new question described in terms of a game he called them the ‘imitation game’ as follows:

The game “… is played with three people, a man (A), a woman (B), and an interrogator (C) who may be of either sex. The interrogator stays in a room apart from the other two. The object of the game for the interrogator is to determine which of the other two is the man and which is the woman. He knows them by labels X and Y, and at the end of the game he says either 'X is A and Y is B' or 'X is B and Y is A'. The interrogator is allowed to put questions to A and B thus:

C: Will X please tell me the length of his or her hair?

Now suppose X is actually A, then A must answer. It is A's {p.434}object in the game to try and cause C to make the wrong identification. His answer might therefore be

'My hair is shingled, and the longest strands, are about nine inches long.'

In order that tones of voice may not help the interrogator the answers should be written, or better still, typewritten. The ideal arrangement is to have a teleprinter communicating between the two rooms. Alternatively the question and answers can be repeated by an intermediary. The object of the game for the third player (B) is to help the interrogator. The best strategy for her is probably to give truthful answers. She can add such things as 'I am the woman, don't listen to him!' to her answers, but it will avail nothing as the man can make similar remarks.

We now ask the question, 'What will happen when a machine takes the part of A in this game?' Will the interrogator decide wrongly as often when the game is played like this as he does when the game is played between a man and a woman? These questions replace our original, 'Can machines think?' Then the article in Section 3 co continues with determining the meaning of the computer. Turing refers to the circumstances concerning the computer he has in his mind. Turing writes:

“It is natural that we should wish to permit every kind of engineering technique to be used in our machines. We also wish to allow the possibility than an engineer or team of engineers may construct a machine which works, but whose manner of operation cannot be satisfactorily described by its constructors because they have applied a method which is largely experimental. Finally, we wish to exclude from the machines men born in the usual manner”. Following the previous suggestions he concludes that only digital computers are permitted to take part in his imitation game. In connection to the digital computers he refers as to the historically first machines of such type to Charles Babbage, who, according the Turing remark at the end of the Chapter 4 of (Turing, 1950) has planned (but never constructed) such a machine – the so called *analytical engine*.

Concerning digital computers he emphasizes that the idea behind them may be explained by saying that this type of machines are intended to carry out any operations which could be done by a human computer who is supposed to be following fixed rules as “supplied in a book” and he (the *human* computer, sic!) has no authority to deviate from them in any detail. With respect to digital computers he emphasizes that they are regarded as consisting of three basic architectural components: *the store* (the memory in today’s terminology), *the executive unit* (the processor in the today’s terminology), and *the control* (the program in today’s wording).

In Section 5 of (Turing, 1950) the universality of digital computers are discussed with only small references to the formal model proposed in (Turing, 1936), and without any reference to the formalized notion of the universal a-machine. However, he mentioned, informally and without referring to the formally precise definition or the corresponding proof to the universality of the digital computers. But this remark evokes more the idea of a really existing hardware rather than of an abstract, formalized device. After that Turing reformulates his original question ‘Can machines think?’ into the equivalent form of ‘Are there imaginable digital computers which would do well in the imitation game?’

Let us turn off the Turing’s original flow of argumentation in this moment, and focus to the formalized meaning of the universal Turing machine and to its capacity to compute any Turing-computable functions in the sense sketched in the previous Section of the present article. The last formulated question then looks like follows: “Are there imaginable a system of Turing-computable functions (a mutually interconnected system of such functions of this property, so a composed function) which would do well in the imitation game?” But having in the mind of the universality property of digital computer, we have the question in the form from the end of the Chapter 5 if (Turing, 1950):”Let us fix our attention on one particular digital computer C. Is it true that by modifying this computer to have an adequate storage, suitably increasing its speed of action, and providing it with an appropriate program, C can be made to play satisfactorily the part of A in the imitation game, the part of B being taken by a man?”

We can conclude that the Turing machine and the Turing test are strongly connected in this point which emphasized the deep strong connection not only between computer programming and the field of Artificial Intelligence, but also the similar connection between the theory of abstract computing and the AI research. The above formulated original questions might be reformulated into a more general form of *‘Be the human intelligence transformable to the form of any Turing-computable (interconnected system of) functions?’* Let us call the positive answer to tis question as the baseogf the *2nd Turing hypothesis*.

4 Morphogenesis and Turing’s 3rd Hypothesis

The purpose of (Turing, 1952) is to discuss a possible mechanism by which the genes of a zygote may determine the anatomical structure of the resulting organism. The theory, according Turing's words, does not make any new hypotheses. It merely suggests only that certain well-known physical laws are sufficient to account for many of the facts. Continuing in the station of the abstract of (Turing, 1952) we read that ‘it is suggested that a system of chemical substances, called morphogens, reacting together and diffusing through a tissue, is adequate to account for the main phenomena of morphogenesis‘ and that ‘A system of reactions and diffusion on a sphere is also considered.‘ This first look to the abstract is sufficient for strengthen our conviction that the article contains some pioneering steps in the field developed today e.g. in the frame of so called membrane computing or molecular computing. So let us focus our attention to (Turing, 1952) form the position of bio-inspired computation, ore specifically form the standpoint of membrane computing.

‘The theory which has been developed here’, resumes Turing the (Turing, 1952) ‘depends essentially on the assumption that the reaction rates are linear functions of the concentrations, an assumption which is justifiable in the case of a system just beginning to leave a homogeneous condition. Such systems certainly have a special interest as giving the first appearance of a pattern, but they are, he point out, the exception rather than the rule. Most of an organism, most of the time, is developing from one pattern into another, rather than from homogeneity into a pattern. One would like to be able to follow this more general process mathematically also. The difficulties are, however, such that one cannot hope to have any very embracing *theory* of such processes, beyond the statement of the equations. It might be possible, however, to treat a few particular cases in detail with the aid of a digital computer.’

Turing recognizes two basic possibilities of how the digital computer might make useful for the research of some of biochemical phenomena: First, he suppose that computer simulations might allow simplifying assumptions required if we decide to use another approaches to the formal study. Second, he recognizes the approaches which use computer simulations make possible to take the “mechanical” aspects of the modeled reality into account during the study. Moreover, he add a very short but from today perspective important comment to the previously mentioned advantages writing: ‘Even with the (…) problem, considered in this paper, for which a reasonably complete mathematical analysis was possible, the computational treatment of a particular case was most illuminating‘ (Turing, 1952).

The proposal to be interested in computational aspects of chemical and biological structures and processes become into the focus of many of present days research activities. As an example from the large spectrum of approaches we mention as an example the so called *membrane computing paradigm* presented in (Paun, 2002). Paun characterizes the membrane systems – the basic computing machinery of the membrane computing) as a “... distributed parallel computing devices, processing multisets of objects, synchronously, in the compartments delimited by a membrane structure. The objects, which correspond to chemicals evolving in the compartments of a cell, can also pass through membranes. The membranes form a hierarchcal structure – they can be dissolved, divided, created, and their permeability can be modified. A sequence of transitions between configurations of a system forms a computation.“ The monograph (Păun, 2002) form the Preface of which we cited the previous strokes contains tens of theorems concerning the computational power of different variations of the membrane systems in comparison with the different computing models (more often formal grammars) but also with the (universal) Turing Machine. The result proves the existence of certain variations of membrane systems which are equivalent with the Turing Machine with respect their computational power.

In the consequence of that and from the perspective followed in this contribution we can conclude the third version of the Turing hypothesis, the *3rd Turing Hypothesis* and formulate it in the following form, for instance: Biochemical systems are able – at list in principle – perform all computations performable by the universal Turing Machine.

This hypothesis competes in certain sense our speculations providing a possibility for us to mention the surprising conclusions: The computation as defined by the universal Turing Machine, the human ability to perform intellectual tasks, and the nature of biochemical (living) systems are in their certain their capacities (almost) identical. The computation, mind, and life are in certain sense the same phenomena… Can it be true? In what sense?

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5 Conclusions

In summary, the contribution proposes an integrative view to the three basic initiatives of Alan M. Turing to the development of the 20th Century origin of the theoretical computer science, and to the development of computationally influenced researches during the past decades. The integrative power lies on the formulation of the so called Church-Turing Thesis on the generality of the Turing machines end their supervalance or equivalence with other computing devices proposed up to now, and in the demonstrated possibility to formulate other two hypotheses which make a bridge between theoretical study of computation, and fields like artificial intelligence – in which the classical Turing test can be formulated as a variation of the Church-Turing Thesis – and artificial life (natural computing), where the proposed variation guides to the hypothesis that computational models of the processes and phenomena taking place in the living organisms require also nothing more general than the Turing Machine can provide for modeling them formally.

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