Čapek, Turing, von Neumann, and the 20th Century Evolution of the Concept of Machine

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Abstract: During the 20th century, the concept of the machine in science and in society changed almost completely. This contribution sketches two ways – the way of literature (and theatre), and the way of science – of this change initiated by highly influential personalities of the 20th century – by the (play)writer Karel Čapek, by mathematicians Alan M. Turing and John von Neumann, and by many others.

1 Introduction

The traditional and broadly accepted definition of the machine is related with physics. A machine is considered as a physical system working deterministically in basic physically well-defined cycles, built by the man, and intended to concentrate the dispersion of the energy in order of doing some physical work. A famous example of such type of the machine is the steam-engine which predestinated the evolution of the whole industry during the 19th century. The past and the present-days computers may be understood as such type of machines, too, and – at least in certain extent – also the living (in biological sense) entities satisfy the above conditions.

The dramatic increase of the use of traditional machines doing physical work started during the 19th century industrial revolution, and accelerated during the 20th century thanks to the machines intended for information processing caused dramatic scientific as well as social and cultural changes, and considerably influenced also the self-image of the western mankind. "*Am I a man or am I a machine?*" the philosopher Jean Baudrillard asked his colleagues at *Ars Electronica* in Linz (Austria) in September 14, 1988, and he answered immediately: "*Virtually and physically we are approaching machines*"[1].

Where has the Baudrillard's idea (and many similar ideas appearing so often in contemplations of so many western intellectuals during the 20th century) its roots? We will focus to this question, and in the following few sections we will show at least two of such roots, one in the artistic culture of the century, in the literature an dramatic art, and the second one in its science and engineering (of computing and computers).

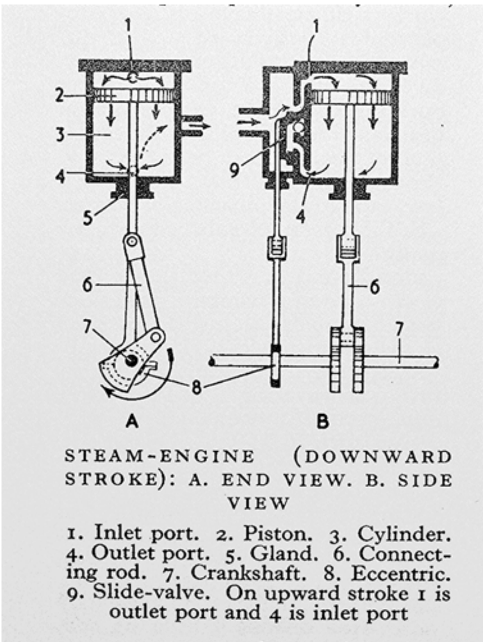

Fig. 1: The scheme of the Steam-Engine (from *The Oxford Illustrated Dictionary,* 2nd Edition, 1975)

[1] The writte vesrion of the lecture is published as (Baudrillard, 1989).

2 Čapek's Robots

It is commonly known that the word *robot* appeared first in the play *R. U. R.* (Rossum's Universal Robots) by the Czech writer and journalist Karel Čapek (1890-1938). He wrote the *R. U. R.* during his and his brother's Josef (1887-1945) vacation in the house of their parents in the spa Trenčianske Teplice (now in Slovakia) during the summer 1920 reflecting in it all the above mentioned intellectual, political, social and artistic influences. As Karel Čapek has mentioned[2], the first name he gave to his "artificial workers" was *labors*. But he wasn't satisfied with this word – it sounded too academically to him – and he asked his brother for help. Josef "in passing" suggested the word *robot*, derived etymologically from the archaic Czech *robota* what means – alike in the Slovak language of these times – the *serfs obligatory work*.[3]

The official first run of *R. U. R.* was in the Prague National Theatre in January 25, 1921 under the direction of Vojta Novák. Costumes have been designed by Josef Čapek. The first night was a great success. Many theatre critics observed a cosmopolitan character of it, the originality of the theme, and anticipated a world-vide success of the play.

Karel Čapek opened by his play perhaps two among the most appealing topics of the 20th century intellectual discourse – the problem of human-machine interaction and the problem on human-like machines. Reflecting the social and political situation of Europe immediately after the end of the World War I, he intended robots first of all as a metaphor of workers dehumanized by the hard stereotypical work, and consequently as an easily abused social class.

Fig. 2: The brothers Karel and Josef Čapek (photo from 20ties of the 20th century).

[2] In the Prague newspaper *Lidové noviny* (December 24, 1933).

[3] More about how the *R. U. R.* started see e.g. in (Horáková, Kelemen, 2003).

From the artistic point of view, the artificial humanoid beings used by Čapek in his play may be understood also as his humanistic reaction to the trendy concepts dominating the modernistic view of human beings in the first third of the 20th century – the concept of a "new man" – e.g. in symbolist theater conventions, in expressionism, in cubism etc. Remind also the futurists yearning for mechanization of human and their adulation of the "cold beauty" of machines made by steel and tubes often depicted in their artworks as well as the political implications of futurism[4]. In such an intellectual clime, contemplating on how the machines work, Karel Čapek expressed in *R. U. R.* his misgiving on what may happen with human beings and with the mankind.

3 The Turing Machine

As Hodges (cf. 1983, Chapter 2) inform us, in the spring of 1935, when his dissertation went the rounds of the King's Fellow at Cambridge University, Alan Mathison Turing (1912-1954) went to a course on foundations of mathematics given by M. H. A. Newman.

Newman's lectures finished with the proof of Kurt Goedel's famous undecidability theorem, which did not rule out of the possibility that there was some way of distinguishing the provable from the non-provable statements. Newman put a question to his students: Was there a *mechanical* process which could be applied to a mathematical statement, and which would come up with the answer as to whether it was provable? The phrase "mechanical process" revolved in Turing's mind and leads him to a question: What would by the most general kind of machine that deals with symbols? Inspired by a mechanical typewriter Turing invented and described with all of necessary mathematical rigor an idea of such machine called then Turing Machine[5].

The Turing Machine consists in two basic parts: the control engine, and the writing head. The writing head is able to read and (re)write symbols appearing in

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[4] Futurism initiated in Filipo T. Marinetti's *The Founding and Manifesto of Futurism* (published in the newspaper Le Figaro) in 1909. Marinetti proclamed the emphasis on discarding the static and unimportant art of the past and rejoicing in the turbulence, originality, and creativity in art, culture, and society and professed the importance of new technology (automobiles, airplanes, locomotives etc., all mechanical devices par excellence) because of its power and complexity. In his writing War, the Worlds Hygiene from 1915 Marinetti in fact joined the just borning ideas of fascism. The Čapek brothers were definitely shaped democrats.

[5] It was done by Alonzo Church in his review of (Turing, 1936-7) in the *Journal of Symbolic Logic*.

the bi-directionally potentially infinite tape divided into discrete squares. The writing hand is able to write a specific symbol (say the symbol 1) into a square on

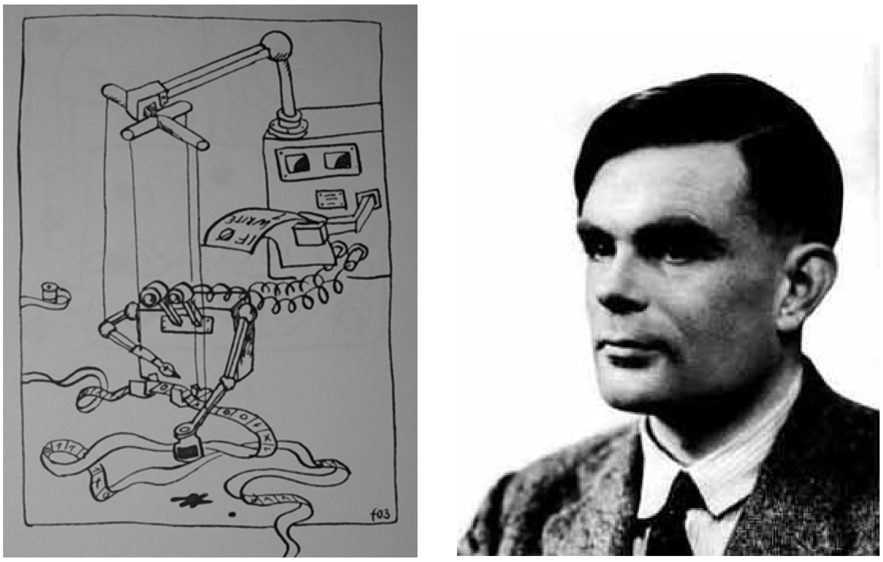

Fig. 3: The Turing Machine as depicted in (Kelemen, Markoš, 2004), and its inventor A. M. Turing.

which it just staying on or to withdraw the symbol form this square. The control engine governs the writing hand actions by four commands: write, erase, move one square to the right, and move one square to the left.

Alan Turing in (Turing, 1936-7) has invented an abstract “mechanical” (mathematically well-defined and rigorously constructive) method (an abstract “machine”) and he proved – roughly speaking – that this “machine” is the most universal one dealing with symbols. Moreover, he proved that form the perspective of this “machine”, the answer to the above mentioned Newman’s question is definitely “no”. In other words he gave the exact mathematical proof of the statement that there exist mathematically well-defined functions for which their values cannot be computed from their variables.

Turing’s idea and the results he proved using it revolutionized the mathematics and – two decades later – give the base for the rapid development of theoretical computer science. First of all, Turing demonstrated that the idea of a machine is important not only from the positions of physics. That it is a general idea, which gives a possibility for rigorous study of not only the physical limitations, but also our own intellectual limitations. Starting by Turing, the idea of the machine started to serve not only the technological progress, but also the critical self-reflection of the mankind own abilities and the intellectual boundaries (of mathematization and the application of computing).

4 Von Neumann's Architecture and Automata

In 1912 when Alan Turing was born, Margittai Neumann János Lajos (1903-1957) was the nine-years old boy living in Budapest as a son of a Hungarian banker. In late 1944, as a US citizen John von Neumann, and as a distinguished theoretical physicist and mathematician, he joined the development team of one among the first electronic computers over the world – the EDVAC[6] Project – as an adviser. The project was in certain extent inspired by the 19th century English mathematician Charles Babbage's idea expressed in the design of his planned *Analytical Engine*. The *Analytical Engine*, as planned, would be able to ingest an unlimited number of instruction cards for its control (programming) using instruction cards. One among the previous 20th century computers, Howard Aiken's MARK II, solved the same problem using a sort of pianola roll. However, the intension of the EDVAC Project was to improve the existing idea of the ENIAC[7] – an *electronic* computer which development begun in the spring 1943 at the University of Pennsylvania. The operations of the ENIAC, being electronic, would be so fast as to make it impossible to supply instructions mechanically. On the ENIAC the instructions supply for each job was arranged using a systems of external devices similar to the manual telephone exchange. The advantage of this solution was that the instructions would be available instantaneously, once the plugging work was done. The disadvantage was twofold: (1) the sequences of instructions are limited in length, and (2) it would take a very long time (a day or so) to do the plugging.

Joining the EDVAC Project, John von Neumann proposed to take leave of a traditional but wrong idea that the data (numbers) and the program (the stock of instructions how to operate on data) are entirely different kind of entities. Instead of that, in the *Draft Report on the EDVAC* dated June 30, 1945 and signed by von Neumann we can read the following important strokes proposing the core of the idea of the von Neumann's computer architecture: "*The device requires considerable memory. While it appeared, that various parts of this memory have to perform functions which differ somewhat in their nature and considerably in their purpose, it is nevertheless tempting to treat the entire memory as one organ*". John von Neumann, inventing how to arrange the sequences of acts performed with data in computers, was perhaps inspired by the introspective evidence that the human plans on what to do and how with data in our minds are somewhere in our minds. In his posthumously published book (Neumann, 1958) is the idea of such similarities (and differences) of the computer and brains explained in certain

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[6] EDVAC states for Electronic Discrete Variable Calculator.
[7] ENIAC states for Electronic Numerical Integrator and Calculator.

details. According the plausible hypothesis that human memory is not passive, but that it is entirely involved in organizing human (intellectual) activity, he transformed the hypothesis into construction of machines, and the hypothesis starts to work! Contemplating on how the human mind works von Neumann improved abilities of machines.

The general-purpose von Neumann style digital computers provided an excellent opportunity to for studies of the kind anticipated by the late von Neumann who pointed out (Burks, 1970, p. 3) that while the past science has dealt mainly with problems of energy, power, force, and motion, the future science would be much more concerned with problems of control, programming,, information processing, communication, organization, and systems. This conviction was very similar to the Norbert Wiener's one. However, von Neumann wished a common theory of man made as well as natural systems with more emphasize placed on logic and computation (an automata theory), while Norbert Wiener's cybernetics proposed in (Wiener, 1948) was oriented more around physiology and control engineering.

One among the most important properties of living systems distinguishing them from the non-living systems is the ability of living systems to reproduce, and von Neumann's big dream was to propose such an automaton. Starting form the idea of Turing Machine he contemplate on automata who produce not sequences of 0s and 1s in a tape, but new automata equivalent with respect of their complexity with their "parents". His design consists – very roughly speaking! – in the following three phases[8]:

a) An automaton **A,** which is able to construct an arbitrary well-described automaton. However, the description has not the form of symbols on a tape, but the form of a combination of basic construction elements in an environment. Let this description is denoted by **I**.
b) An automaton **B,** which is able to make a copy of **I**.
c) Let **A** and **B** are combined with a control unit **C** thank to which **A** will construct an automaton according the description **I**, then **B** will produce a copy of **I**, and finally **C** will put the just produced **I** into the automata constructed by **A**. Finally **C** separate the "newborn" automaton form the systems **A+B+C**.

Denote the **A+B+C** by **D**. In order to work, it is necessary to implement the process described in c) into the part **A** of **D**. So, let us construct a description $\mathbf{I_D}$ of **D** and implement it into **A**. Let the obtained automaton is denoted by **E**. Then **E** is – obviously, writes von Neumann, but the result he never proved with mathematical rigor by him – form the point of view of Turing-computability a realistic and *self-reproducing* automaton.

[8] We follow the description presented by John von Neumann in his lecture given at the Hixton Symposium, Pasadena, Cal., Sept. 20, 1948, and published in an edited form as (Neumann, 1951).

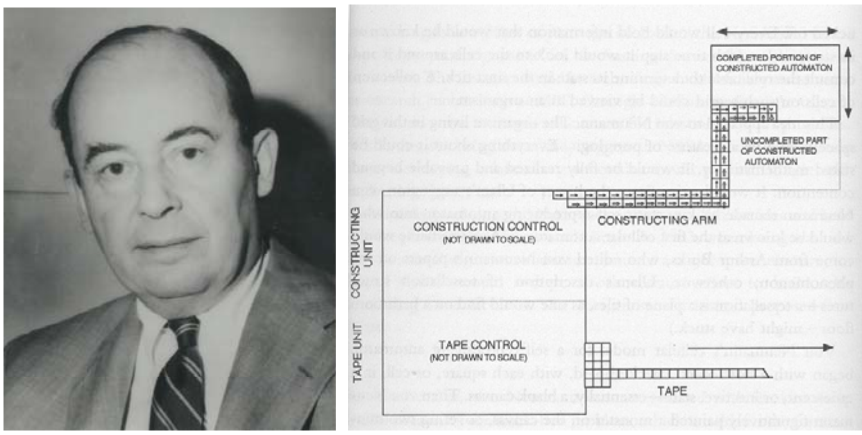

Fig. 4: John von Neumann, and his Self-Reproducing Automaton working on in an environment having the form of a two-dimensional grid as described in details in (Burks, 1970). The picture inspired by that one appearing in (Burks, 1970) is taken from (Levy, 1992).

John von Neumann proposed his self-reproducing automaton in the form of an artificial multi-cellular system, an artificial organism composed from different types of "organs" composed from different types of "cells" having simple computational properties which production required 29 possible internal states of a "cell". However, he never completed the written proof of the properties of the proposed model. The complexity of description of the subject was more then he had anticipated, and he shelved it when he was appointed to the U. S. Atomic Energy Commission. When his health was failing, he allowed John Kemeny (the later inventor of the programming language BASIC) to write an article on self-reproducing cellular automata[9].

In order to make the theoretical analysis of the idea cellular automata and of the process of self-reproduction of computational systems possible, the von Neumann's original highly complex a technically hardly manageable idea must be simplified. This simplification has been made by E. F. Codd, e.g. by reducing the "cells" internal states from 29 to 8 in such a way that the resulting self-reproducing cellular automata model preserved their computational universality in the sense of Turing. The proposed model has been systematically studied and then presented in the form of a monograph (Codd, 1968).

Further simplification of the model has been made – in order to program the first computer simulation of self-reproducing cellular automata – by Christopher Langton. Langton's intention was not to preserve the property of computational

[9] Kemeny's article published in *Scientific American* (April 1955, pp. 58-68) advocates the these that there are no conclusive evidence for a principal gap between man and a machine.

universality of the model. He was looking for the simplest implemented cellular configuration that could reproduce itself not only theoretically, but also in its computer simulated form, and he found one![10] Moreover, the proposed and the implemented model – the *life, as it could be* – contains some significant similarities with real living systems – with the *life, as we know it* – e.g. the genotype/phenotype distinction and some others.

The phrases emphasized by italics are from Langton's pioneering paper (Langton, 1989) which initialized the new branch of scientific and engineering activities known now as *Artificial Life* (AL) which is concerned (complementing the traditional biology concerned – in order to understand life – with the analysis of living organisms) with synthesizing life like behaviors. The key concept of AL is emergence. It is taken for granted that natural life emerges out of the interactions of nonliving molecules with no global "controller" of the behavior of every part. Rather, the behavior of the whole system emerges out from local interactions of the parts.

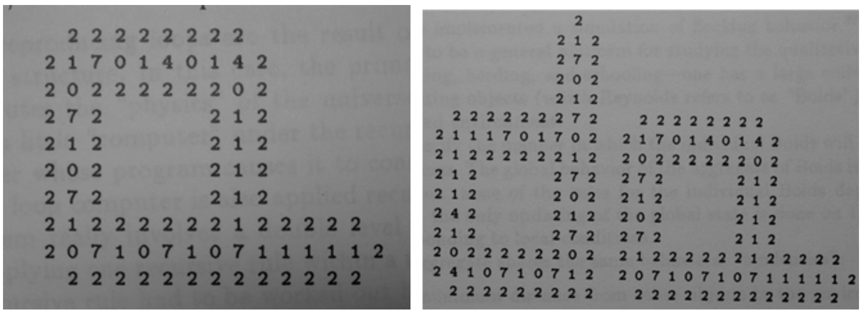

Fig. 5: One among the simplest Langton's structures that can reproduce itself (left). Each number is the state of one of the automata (cells). After 151 time-steps, the structure is succeeded to reproduce itself (right). For more details see (Langton, 1989)

5 The New Concept of Machine

In the Prague newspaper *Lidové noviny* (June 9. 1935) Karel Čapek expressed his opinion concerning robots clearly explaining: **"…***robots are not mechanisms. They have not been made up from tin and cogwheels. They have been built up not for glory of the mechanical engineering. Having the author in his mind some admire of the human mind, it was not the admiration of technology, but that of the science. I am terrified by the responsibility for the idea that machines may replace*

[10] Perhaps the most complete description of Langton's self-reproducing automata is given in (Langton, 1984).

humans in the future, and that in their cogwheels may emerge something like life, love or revolt." However, the author is never owner of his work and ideas. The difference in comprehension of the *R. U. R.* and the overall comprehension of robots inside two cultures with different social, economic, and historic experiences – the European experience after the World Ware I, and the experience of the USA at the same time – has been substantially different. It becomes to be proved very simply, looking and comparing the costumes of the robots from first nights of the play *R. U. R.* in Prague and New York City (see Fig. 6), for instance. In the European context, Čapek's robots was, and still remains a kind of warning against the dehumanization through "mechanization" of human life. In USA the idea of robots was understood as an appeal for making machines much more clever, and for engineers of the pioneering years of cybernetics the only way how to build robots was to combine metal-based mechanics with electro-technique.

Methodologically, the effort to construct robots went in two opposite directions, both based on the significant progress of the computer science and engineering pioneered e.g. by Alan M. Turing and John von Neumann. At the half of the past century an ambitious way of human professional curiosity has been started by Turing's famous paper (Turing, 1950), and then in 1956 named *Artificial Intelligence* (AI). "*...finding useful mechanistic interpretations of* […] *mentalistic notions that have real value* […] *is associated in its most elementary forms with what we call cybernetics, and in its advanced forms with what we call artificial intelligence*" writes Marvin Minsky (1968, p. 2), a cofounder of AI.

During decades of research, two main ways towards this goal have been discovered – the *top down* approach analyzing the human mind from the position of the computational paradigm, and then trying to (re)construct it step-by-step on the base of its computationally precise understanding. Minsky explains this conception in the Prologue of his *The Society of Mind*, (p. 17): "*What can we do when things are hard to describe? We start by sketching out the roughest shapes to serve as scaffolds for the rest; it does not matter very much if some of those forms turn out partially wrong. Next, draw details to give these skeletons more lifelike flesh. Last, in the final filling-in, discard whichever first ideas no longer fit.* " The alternative way proceeds from the *bottom up* synthesizing more and more clever machines behaving rationally in their specific environments. It is supposed that the robot does not need any coherent concept of the outer world. Instead of that they must have efficient possibilities to learn directly from their massive interactions with their environments. A famous project of this orientation – the project Cog – resulted up to now in an upper-torso humanoid robot which approximates human movements, and visual, tactile, auditory and vestibular sensors (Brooks et al., 1999).

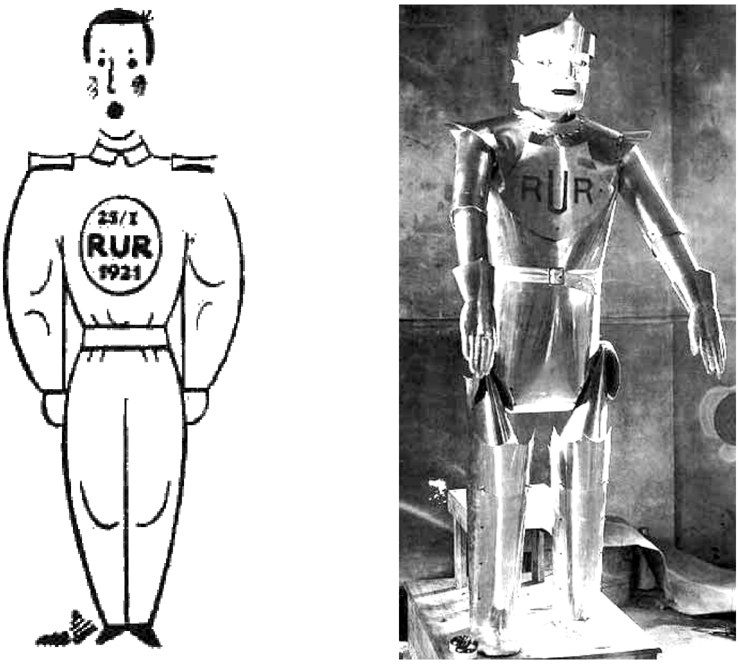

Fig. 6: Costume design of robots (and a caricature of Karel Čapek as a robot) by Josef Čapek for the Prague first night of the *R. U. R.* (left), and the costume design of robots for the first American run of the play in Guild Theatre, NYC, October 9, 1922 (right).

6 The New Concept of Life

In the prologue of the play *R. U. R.* Mr. Domin – the president of the R. U. R. robot factory – recollects the beginnings of the idea of robots for Helena Glory: *And then, Miss Glory, old Rossum wrote among his chemical formulae: "Nature has found only one process by which to organize living matter. There is, however, another process, simpler, more moldable and faster, which nature has not hit upon at all. It is this other process, by means of which the development of life could proceed, that I have discovered this very day." Imagine, Miss Glory, that he wrote these lofty words about some phlegm of a colloidal jelly that not even a dog would eat. Imagine him sitting over a test tube and thinking how the whole tree of life would grow out of it, starting with some species of worm and ending – ending with man himself. Man made from a different matter than we are. Miss Glory, that was a tremendous moment.*

So, as Karel Čapek predicted in his artistic visions, John von Neumann in his scientific contemplations on the power of self-reproducing cellular automata, and as Luc Steels and Rodney Brooks documented in (and emphasized by the title of) their edited volume (Steels, Brooks, 1995) collecting recognized papers relating AL with AI, there exists a continuous way from artificially living to artificially intelligent beings. Maybe the Alan Turing's late interest in the chemical basis of morphogenesis (Turing, 1952) was inspired – at least in certain extent – by his early interests in computational, and later in intellectual capacities of machines, too.

Computers (machines) are involved into the biological research in two principal ways. They are tools for performing traditional computations of output data from some inputs (e.g. in statistics), and for performing dynamic simulations in order to model formally well described biological processes similarly as in other branches of science (physics, chemistry, etc.). The role of computers and machines in general in AL is different. In order to understand life the AL specialists implement their hypotheses concerning life into machines. The machines with implemented hypotheses then start to behave in certain ways and the specialists have the opportunity (first time in the history oh the humankind) to observe the behaviors and compare them with the expectations following from the original hypotheses. In other words: they have the opportunity to test how their hypotheses work. This role of machines in AL is very similar to their role in AI, where the specialists formulate their hypotheses concerning intelligence, and test their hypotheses using machines in a very similar way.

In AI as well as in AL we believe that our hypotheses about intelligence and life will match the reality better and better. Thank to this progress our machines will behave more and more like intelligent and living entities. However, the question whether they will be intelligent and living or not, is – according our opinion – out of the scope of science. It is not a scientific problem, but an ethical one, more generally – a problem which must be solved inside of our culture. The pioneering role of the personalities named in the present contribution consists in including machines into the step-by-step process of understanding the miraculous phenomena of life and intelligence connected *prima face* with living and human beings. Thank to these scientific activities, in our culture appeared an appealing question concerning our own identity, expressed e.g. as Jean Baudrillard formulated it in a rather provoking way as quoted at the beginning of this article.

7 Epilogue

Starting with Baudrillard's questions about the future and the destiny of humankind we have followed the route from early dreams on artificially created humans – the *robots*, as we know the word all over the world, or as *labors* – this was Karel Čapek's original word denoting artificially created humans before he accepted his brother's Josef proposal to use the neologism rooted not in Latin but in Slavonic family of languages – through interests of scientists and engineers in understanding the human intellectual capabilities logically as pioneered by Alan Turing, and then in the framework of their attempts to build man-like machines (von Neumann and Turing again) up to efforts of today AI and AL researchers (represented in the present article by Marvin Minsky, Rodney Brooks, and Christopher Langton). The efforts of the named personalities as well as of many remained unnamed who are working in today AI, advanced robotics, and AL and we may add also many of those working in the field of AL *"...becoming a posthuman means [...] envisioning humans as information-processing machines with fundamental similarities to other kinds of information-processing machines, especially intelligent computers. Because of how information has been defined, many people holding this view tend to put materiality on one side of a divide and information on the other side, making it possible to think of information as a kind of immaterial fluid that circulates effortlessly around the globe while still retaining the solidity of a reified concept. [...] Other voices insist that the body cannot be left behind, that the specificities of embodiment matter, that mind and body are finally the "unit" [...] rather than two separate entities. Increasingly the question is not whether we will become posthuman, posthumanity is already here. Rather, the question is what kind of posthumans we will be* ", writes Katherine Hayles (1999, p. 246),

The play *R. U. R.* ends with the scene in which Karel Čapek depicted his vision of the destiny of his robots (and might be also his vision of the future of humankind). Two robots – Primus and Helena – are faced with the intention of the last human being on the earth, Alquist, to dissect one of them in order to re-discover the miracle of life – the ability of robots to reproduce biologically. But the robots are against the dissection. Instead of the dissection might be the post-humans are born in the closing scene of *R. U. R.*:

Primus: We – we – belong to each other.

Alquist: Say no more. (He opens the center door.) Quiet. Go.

Primus: Where?

Alquist (in a whisper): Wherever you wish. Helena, take him. (He pushes them out the door.) Go, Adam. Go, Eve - be a wife to him. Be a husband to her, Primus.

(He closes the door behind them.)

Alquist: O blessed day! (He goes to the desk on tiptoe and spills the test tubes on the floor.) O hallowed sixth day! (He sits down at the desk and throws the books on the floor, then opens a bible, leafs through it and reads) "So God created man in his own image, in the image of God created he him; male and female created he them. And God blessed them, and God said unto them: Be fruitful, and multiply, and replenish the earth, and subdue it: and have dominion over the fish of the sea, and over the fowl of the air, and over every living thing that moved upon the earth." (He stands up.) "And God saw every thing that he had made, and, behold, it was very good. And the evening and the morning were the sixth day." (He goes to the middle of the room.) The sixth day! The day of grace. (He falls on his knees.) Now, Lord, let Thy servant – Thy most superfluous servant Alquist – depart. Rossum, Fabry, Gall, great inventors, what did you ever invent that was great when compared to that girl, to that boy, to this first couple who have discovered love, tears, beloved laughter, the love of husband and wife? O nature, nature, life will not perish! Friends, Helena, life will not perish! It will begin anew with love; it will start out naked and tiny; it will take root in the wilderness, and to it all that we did and built will mean nothing-our towns and factories, our art, our ideas will all mean nothing, and yet life will not perish! Only we have perished. Our houses and machines will be in ruins, our systems will collapse, and the names of our great will fall away like dry leaves. Only you, love, will blossom on this rubbish heap and commit the seed of life to the winds. Now let Thy servant depart in peace, O Lord, for my eyes have beheld – beheld Thy deliverance through love, and life shall not perish! (He rises.) It shall not perish! (He stretches out his hands.) Not perish!

CURTAIN

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