The Evolution of humanity as driven by evolution of technology

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In this essay I will discuss the future of humanity as abstractly described by an evolutionary process. The main driving force in this process is the development of new technology. I will present a simple (mathematical) model for evolution to discuss questions like: what is the direction of evolution? What is the best state and how can we reach them? The influence of the society is also modeled by the so-called Co-evolution leading to global trends. On these grounds, the future of humanity is quite open only controlled by our free will and our needs.

I. THE PRINCIPLES OF EVOLUTION

In 1964, the polish science-fiction author Stanisław Lem, also known for the book *Solaris*, wrote its first philosophical book *Summa technologiae*. The name is an allusion to *Summa Theologiae* by Thomas Aquinas and to *Summa Theologiae* by Albertus Magnus. Main topic of the book is the discussion of the civilization in the absence of limitations, both technological and material. He also looks at moral-ethical and philosophical consequences of future technologies. Furthermore, Lem had foreseen the development of virtual reality, nanotechnology and artificial intelligence leading to the technological singularity, when artificial intelligence will have progressed to the point of a greater-than-human intelligence (which may be happen within 30 years). Therefore according to Lem, the evolution of technology is the new driving force of civilization and humanity. So, he was also occupied with the question: *How Should Humanity Steer the Future?* But is it true, is technology the driving force for humanity? And more importantly, what is the dynamics or rule for the development of technology? Lets discuss the last question first.

There is a good agreement among scientists that humanity undergoes a biological evolution process over some million years. This biological evolution of the humanity has a very long time-scale and can be neglected in the following. But another component is the world which surround us: all tools, necessary things and equipment collected in the word 'technology'. In the last 300 years, there was an explosion in the development of technology, at least three industrial revolutions. It was the main driving force for the development of the humanity too. The first period is the era of the steam engine, the spinning machine (spinning Jenny) and other machines of pre-mass production. In the second industrial revolution, there was the change to mass production and the utilization of electricity as well the development of chemical industry. Whereas the last two revolutions are mainly concerned with the extension of manpower, the last revolution was a revolution in information technology. Its cause was the invention of the computer and the microchip. Now there is a flood of new information every day which we try to process with the help of computers. But we currently miss the intelligent processing of information which will be denoted as fourth industrial revolution (also sometimes called *Industry 4.0*) leading to artificial intelligence. In this historical process of industrial development, there is no obvious scheme. Every 'revolution' started with a scientific discovery (Carnot process in thermodynamics, electromagnetic induction, field effect in semiconductors etc.) which was used to create new machines or finally to produce more advanced products in less time than before. So, science produced new knowledge which was channeled by the needs of humanity. But the scientific discovery cannot be planned. If we want to model them then we have to use a stochastic process. In contrast, the adaption process of the new scientific knowledge into products is strongly influenced by the needs and by efficiency. We will use only these methods (as developed by new scientific discoveries) which are better (according to some fitness measure). Or, we select all methods which are minimize or maximize some function. But then we obtain an evolution process: a production process (a species) will be modified by new scientific discoveries (a mutation) leading to new possible production processes but we choose one (a selection) by using some criteria (a fitness function). If we accept the evolution of humanity as driven by the evolution of technology then we have to look at evolution as a general process. Therefore we have our first claim:
The development of technology is an evolutionary process in an abstract sense, consisting of mutation and selection.
But how can it be that evolution is an optimization process? And what is the aim of evolution if it exists? In the following I will discuss this idea on mathematical grounds, i.e. I will map the evolution of technology to a simple mathematical model. Evolution was originally introduced by Darwin [Dar59] (and parallel by Wallace) to explain the appearance of new species on earth during the last million years. The evolution can be divided into two steps which are fundamental: mutation and selection. Mutation generates new possible species but this process has no direction. For that purpose one needs the process of selection: the new species are compared to each other (competition). Only the best species are taken for the next mutation step. Mutation can be seen as process to produce new information in an abstract manner whereas selection is a process to channel it in the desired direction. These two steps can be arranged in a simple mathematical model of the evolution which was also used in optimization ([AER97] here is another evolution: my name changed after my marriage). Starting point of the model is an abstract space $\mathcal{M}$, the

space of all species or better the parameter space to characterize the species. Then one introduces a fitness function $f : \mathcal{M} \to \mathbb{R}$. This fitness function can be seen as a kind of landscape over the space $\mathcal{M}$ with many local hills and valleys. The aim of the whole process is the search of the global optimum, i.e. the smallest value of the fitness function f: there is a parameter set $x \in \mathcal{M}$ as a point of the space of species so that $f(x) < f(y)$ for all other $y \in \mathcal{M}$. But how can one implement the selection and mutation process? From the abstract point of view we consider a distribution of searcher described by a density $P(x)$ as function $P : \mathcal{M} \to [0,1]$ normalized to 1 (by integration/summation over $\mathcal{M}$). Mutation is a random process so that a species of sort A goes to a species C with some rate w ($A \stackrel{w}{\to} C$). Selection is a process so that a pair of species (A, C) goes to (A, A) if the fitness $f(A)$ is better then $f(C)$ ($f(A) < f(C)$) or to (C, C) in the other case. The idea of this selection process went to back to Fisher. In 1930, he formulated the so-called fundamental theorem of natural selection, although it uses some mathematical notation, is not a theorem in the mathematical sense, but an idea in population genetics which was originally stated thus: "The rate of increase in fitness of any organism at any time is equal to its genetic variance in fitness at that time." This principle was mathematically confirmed by G. Price in 1972 (the Price equation). For our mathematical model, this selection has tremendous simplification. One need to know only the local property and not the global properties of the fitness. Then it is enough to know the fitness function only locally (for instance as algorithm to produce a number for every species).

Now lets concentrate on the discrete space $\mathcal{M}$ then P_i is the density for species $i \in \mathcal{M}$. Both processes can be described in one time-dependent equation (also called Master or Fisher-Eigen equation)

$$\frac{d}{dt} P_i = \underbrace{\sum_j (w_{ij} P_j - w_{ji} P_i)}_{\text{Mutation}} + \underbrace{(f_i - \langle f \rangle)\, P_i}_{\text{Selection}} \tag{1}$$

with $\langle f \rangle = \sum_i f_i P_i$ as normalization (see appendix A). At this place, we also understand better the meaning of the function P_i. This function P_i is not a real density for the searchers but better a probability distribution to find a searcher at the place i. This interpretation and the matrix equation

$$\frac{d}{dt} P = H \cdot P$$

for (1) revealed a formal connection to the Schrödinger equation but with an important difference: the distribution P is a real function and the time derivative is also real and not imaginary (in physics slang: one made a Wick rotation). This small difference has a tremendous effect: the solution P of equation (1) converges to P_0, the distribution around the global minimum (corresponding to the smallest eigenvalue of H), for large time [AER97]. But in many real problems we have contradicting parameter in the optimization [AER96b]. For instance in a street network with fixed vertices, one has to minimize the length of the streets (because of the costs) but at the same time one has to satisfy the wish for comfort (so maximize the number of streets). Furthermore, the fitness function is often not an explicit function but rather an algorithm to calculate a number for every species. As an example consider the problem of protein folding. For every protein configuration, one can calculate the free energy. Its minimization is the solution of the problem. But a small change of the protein configuration has sometimes a large effect on the free energy.

For the development of the technology, we have the same principles. Driving force is science abstractly described as a mutation of technology. But this force is not directed. Or with other words: we don't know the practical relevance of new scientific discovery. Then we develop new technologies from this discovery but select one or two technologies along our needs (as expression of fitness). Therefore we know locally the direction of the evolution but not globally. Currently we don't consider the relation between technologies which will be discussed now.

II. CO-EVOLUTION OR THE INFLUENCE OF TRENDS

The development of technologies is not a single process. Every newly developed technology depends on the previous one or influenced the next new technology. It is like in the animality: the fitness for the selection process is formed by all animals but not by an abstract measure. The same effect should be important for the evolution of technologies too. From the point of physics, one has an interaction between two species. This interaction can be abstractly understood as an exchange of information between the two species. The simplest possible interaction (see appendix B for a derivation) leads to the following modification of equation (1)

$$\frac{d}{dt} P_i = \underbrace{\sum_j (w_{ij} P_j - w_{ji} P_i)}_{\text{Mutation}} + \underbrace{(f_i - \langle f \rangle)\, P_i}_{\text{Selection}} + \underbrace{g\,(P_i^2)\, P_i}_{\text{Co-evolution}} \tag{2}$$

with the interaction constant g. For $g > 0$ the interaction is attractive and for $g < 0$ repulsive. For the following we will consider $g > 0$. What is the effect of this term? It has a self-reinforcing effect: a small clustering of species (with a critical number of species) around the optimal fitness value will end in a peaked distribution (of all species) at this value. This behavior reminds on Bose-Einstein condensation and the formal similarity of the equation (2) with the Gross–Pitaevskii equation explained this property. In our case (the evolution of technology) one can interpret the behavior: a technology must be not only good (or with good fitness) but it must also assert against other technologies. This effect can be achieved by an interaction between species (as we propose by the equation above). Now if a specific number of species are 'convinced' then all other species will 'follow'. It is what we call a trend. Apples iPhone is not always better then other SmartPhones but anybody think it is. Even, people speak with other about it ("Did you got the new iPhone? It is amazing."). If this kind of communication will achieve a critical value then the new technology will become accepted. Therefore, a trend has its root in the interaction/communication.

III. WHAT IS THE DIRECTION OF EVOLUTION?

Now let us collect the results of our simple model. We studied the evolution of humanity driven by the evolution of technologies. By our argumentation above, it is possible to define a simple model for evolution which can also explain the evolution of technologies. We see the driving force of every new technology in new science discoveries. But these discoveries are more or less random, i.e. we cannot foresee it. So, these discoveries are comparable to mutation in evolution. The direction of evolution will be dictated by the fitness function, i.e. the answer to the question: what is the technology which fulfills our needs. But the whole dynamics is purely stochastic, i.e. the whole evolutionary process is not deterministic. We don't know when and how we arrive at the global optimum. But more importantly, we are not isolated individuals. Humanity is a strongly connected network of information exchange which influenced also our needs. This aspect was called Co-evolution, i.e. there is no absolute fitness function. Then the direction of evolution is more uncertain: the process will end in a (maybe local) optimum but anybody is satisfied with this state following the general trend. I strongly believed that humanity will steer the future according to these principles.

IV. WHAT IS THE FINAL STATE OF EVOLUTION?

We described a simple model of evolution above. In particular we expected that all properties of the simple model will be also fulfilled by realistic evolutionary process like the future of technology or of humanity. A lesson which can be learned from our simple model is the achievement of a final state in evolution. Does evolution really ends? Given a mathematical function then we have in most cases one global optimum. But in all realistic cases we have only an algorithm to calculate the fitness for a species. We don't know the spectrum of possible fitness values and therefore we will never know the global optimum. With this simple thoughts we obtain a main principle of evolution: it will never ends. And we expect also the same behavior for the evolution of humanity (whatever the driving force is, technology or any other possibility). So the question: *What is the best state that humanity can realistically achieve?* has no real answer.

V. HOW SHOULD HUMANITY STEER THE FUTURE?

Above I discussed the possible future of humanity as an evolutionary process. In a simple model one can study the properties of evolution. Finally we can state:

- Evolution is a stochastic process with a local but not global direction. Evolution of technology is driven by science (as mutation) and selected by all of us.
- Evolution never ends, i.e.we don't know whether the best state is realized.
- The local direction of evolution is not only determined by the quest to reach a better state but also by the common needs of the group.

Therefore to express it simply: there is no general plan for the future of humanity but we all together will do it. Nevertheless there are general trends (or possible mutations) or my guess for three of them are:

1. Artificial intelligence: Usual computers are at the border today. The flood of information can be only handled by intelligent algorithms. The central instance of a computer (the microprocessor) should be exchanged by a dynamical network of communicating devices (like our brain), a non-von-Neumann architecture.

2. Nuclear fusion: The energy crisis in the near future can be prohibited by nuclear fusion, i.e. we should spark a new sun on earth. The risk of this technology is low comparable to nuclear fission.

3. New materials: With the help of nanotechnology, we will invent totally new kinds of materials.

or we will invent completely other things. Who knows, evolution has no global direction. But what are the risks of this process? It is an evolutionary process again with all necessary trails-and-errors. I don't see another way....

Before concluding, I must add that the views expressed are only partly original. I have partially drawn from the discussions with Helge Rosé and Werner Ebeling. I was also influenced by the work of S.Lem.

Appendix A: ONE SIMPLE MODEL OF EVOLUTION

As stated above, evolution consists of two processes: mutation and selection [AER96b, AER96a, AER97, Aße97]. Lets start with the mutation process. It is a stochastic process which depends only on the previous time step or a Markow process determined by the Chapman-Kolmogorow equation

$$P(x_i, t+\tau+\sigma|x_j, t) = \sum_k P(x_i, t+\tau+\sigma|x_k, t+\sigma)\, P(x_k, t+\sigma|x_j, t)$$

for the transition matrix (conditioned probability) $P(x_i, t|x_j, \tau)$. The transition from a state $x_j(t)$ to $x_i(t+\tau)$ is determined by the probability $v_j(t)\tau$ (with the rate $v_j(t)$). With this rate we can write for the transition matrix

$$P(x_i, t+\tau|x_j, t) = (1 - v_j(t))\delta_{ij} + v_j(t)\tau\, W_{ij}(t) + O(\tau)$$

and with $w_{ij}(t) = v_j(t)\, W_{ij}(t)$ one obtains for the probability $P_i(t) = P(x_i, t)$ the equation

$$\frac{P_i(t+\tau) - P_i(t)}{\tau} = \sum_j w_{ij} P_j(t) - w_{ji} P_i(t)$$

or in the limit $\tau \to 0$

$$\frac{d}{dt} P_i = \sum_j \left(w_{ij} P_j - w_{ji} P_i\right) \tag{A1}$$

the dynamics for the mutation (Master equation). For the selection process using the fitness function F_i for species i, one can use a 2-particle reaction with the transitions

$$(i,j) \begin{cases} \xrightarrow{|f|} (i,i) & : \quad f_i > 0 \\ \xrightarrow{|f|} (j,j) & : \quad f_i < 0 \end{cases}$$

and the fitness proportional rate $f_i = \langle F \rangle - F_i$ and $\langle F \rangle = \sum_i F_i\, P_i$. This process can be expressed in a rate

$$w_{ij} = |f_j|\Theta(-f_j) + f_i \Theta(f_i)$$

and put into the Master equation (A1) to obtain the so-called Fisher-Eigen equation

$$\frac{d}{dt} P_i = \left(\langle F \rangle - F_i\right) P_i$$

for the selection process where we implicitly assume no correlations (i.e. $P_{ij} = P_i \cdot P_j$). Both equations (mutation and selection) together are our model for evolution:

$$\frac{d}{dt} P_i = \underbrace{\sum_j \left(w_{ij} P_j - w_{ji} P_i\right)}_{\text{Mutation}} + \underbrace{\left(f_i - \langle f \rangle\right) P_i}_{\text{Selection}}$$

Appendix B: CO-EVOLUTION

Now we will implement the interaction between the species. Here we use the correspondence of the discrete equation (1) to an equation over a continuous space. Then mutation is modeled by a diffusion process (with the Laplace operator as term $D\triangle$). Finally we obtain the equation

$$\frac{\partial}{\partial t}P(x,t) = D\triangle P(x,t) + (\langle F\rangle - F(x))\,P(x,t)$$

now with

$$\langle F\rangle = \int F(x)P(x,t)dvol(x)\,.$$

The term $\langle F\rangle$ is a simple normalization term which can be neglected for simplicity. Then we rewrite the equation above as

$$\frac{\partial}{\partial t}P(x,t) = \frac{\delta}{\delta P}\mathcal{L}[P]$$

with the functional

$$\mathcal{L}[P] = \int\left(\frac{D}{2}(\nabla P)^2 + \frac{1}{2}F\,P^2\right)dvol(x)$$

In the 'language' of field theory, it is the Lagrangian

$$L = \frac{D}{2}(\nabla P)^2 + \frac{1}{2}F\,P^2$$

with the 'scalar field' P. Now the pairwise interaction can be implemented by a term P^4 in the Lagrangian, a 4-field interaction known also as Fermi interaction. Then we obtain

$$L = \frac{D}{2}(\nabla P)^2 + \frac{1}{2}F\,P^2 + gP^4$$

and finally

$$\frac{\partial}{\partial t}P(x,t) = D\triangle P(x,t) + (\langle F\rangle - F(x))\,P(x,t) + (P(x,t))^2P(x,t)$$

which can be translated back to

$$\frac{d}{dt}P_i = \underbrace{\sum_j (w_{ij}P_j - w_{ji}P_i)}_{\text{Mutation}} + \underbrace{(f_i - \langle f\rangle)\,P_i}_{\text{Selection}} + \underbrace{g\,(P_i^2)\,P_i}_{\text{Co-evolution}} \quad .$$

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