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TRIZ Evolution Trends in Biological and Technological Design Strategies

N. R. Bogatyrev, O. A. Bogatyreva
Department of Mechanical Engineering, The University of Bath BA2 7AY, UK
ensnb@bath.ac.uk; ensob@bath.ac.uk

Abstract

The concept of evolution in technology and biology is discussed. It appears that most of the evolution trends in technology and biology result from different development strategies. This conflict has roots from the time when technology emerged to adapt *the environment* for our needs. Following that strategy to full extent is dangerous. We need also to adapt to *the environment*, but current technology neither has the mechanisms for such changes nor the knowledge of which directions to go. Therefore learning from nature is a real challenge. We suggest ten new evolution trends for strategic design to be ahead on future markets.

Keywords:
TRIZ, Evolution, Bio-Inspired Design

1 INTRODUCTION

The trends of a product evolution developed in TRIZ are very helpful in product design and strategic management for choosing the best financial investment. Obviously the best way to predict the future is to design it. It is well known in TRIZ that at each different stage of product development (expressed by an S-curve) different evolutionary trends are applicable. Actually all the trends reflect how often we use the particular sets of inventive principles or standards. In other words they reflect the pattern of our thinking we have become used to. G. Altshuller extracted inventive principles and revealed his laws of evolution of technical systems from the analysis of a huge number (figures vary around 3 million) of patents. As these trends reflect the popularity, and success, of some particular inventive principles amongst engineers there is a question whether these pathways are programmed as working patterns in the mind or "TRIZ-defined" and belong to technology as an artificial phenomenon? In other words, are these principles (evolution trends) inherited or invented? So, basically we face the question: are there any general laws of nature reflected in technology development that gave to G. Altshuller [1] the idea of technological evolution trends? If the evolution trends are "invented" are they always good to follow? In this paper we describe our quest to find the answer.

Using TRIZ we certainly learn from past experience and transfer our thinking patterns to provide the future technology's development. But what if we need to adapt current technology to the totally new conditions where past experience is not valid anymore? G. Altshuller and M. Rubin [2] described what will happen after "the final victory of technology" in its opposition to nature. The main message of that paper is that technology suppresses nature, replaces it with artefacts in our life and finally, inevitably, we will come to the point where we will live in totally artificial environment. (Any professional ecologist will also say that after this stage the days of humankind will be numbered, but this is another story). Thinking about technology and nature as two contrasting opposites is a common ideology from the past. The future looks very pessimistic if technology will be following the same trends. Yes, at the very beginning technology was designed to extend our abilities, to replace some of our functions with machines carrying out work much better than we can. But technology has changed dramatically today. With the development of information technology and new materials we can now produce machines that may possess many, or even all, of the features of living creatures. We have even started thinking about the self-reproduction of machines: engineers have already designed and built a set of modular robots that can be combined into machines of varying sizes that will in turn be able to construct identical copies of themselves [3], [4]. To remain ahead of this new market and make reliable forecasts we need to know what evolutionary trends these new technological "creatures" will follow. In such circumstances the evolutionary trends of the former technology (with its counter-nature ideology) will be no longer valid or applicable and we need to be ready for such changes. We are now at the beginning of a new technological revolution – changing the paradigm of thinking in order to survive. Unfortunately it often happens that we are making our technology "green" simply by using the prefix "eco -". This will not help us survive any future global ecological crisis. We need, carefully and thoughtfully, to include our new technology into the ecosystem of the planet we belong to and pay nature back what we have been credited.

So, the goal of our paper is to provide engineers with the trends and concepts that they need to take into account in the design of the future generation products. Some of these trends are similar to ones defined by TRIZ, but quite a few of the concepts now being learned from nature can provide us with new ideas and strategies for engineering of the future.

To do this we need to define both what is common and what is different in biological evolution and the development of engineering products.

2 BIOLOGY AND TECHNOLOGY – TWO OPPOSITES AND A CHALLENGE FOR SYNTHESIS

2.1 Comparison of living and technical systems

First of all we decided to have a look what are the major differences between animate nature and technology (table 1, 2).

Technical systems are created by humans (biological systems) for themselves for some definite number of purposes. But biological systems possess their own self-value. The use of TRIZ in biology faces serious restrictions which are set by the very features of biological systems which make them alive.

The simplest example: widespread mechanical-engineering methods are based on extremely high or extremely low temperatures however similar methods cannot be applied to the vast majority of living creatures because biological systems will not survive such energy impacts. Living nature is energy efficient and avoids extremes. An ideal technical system and an "ideal" biological system look very different (table 1). For example, a living creature typically needs to put a lot of pressure on the environment to survive (change the environment, which is in fact engineering), but also to be very adaptable (changes itself in response to environment, which is not typical for technology). Another example: the tendency of ideality (i.e. decreasing the size of a device retaining its function) exists in biological systems, but only in some limited cases (for example, parasites). One of the most profound reasons of this might be that the living systems are self-valuable objects of and for themselves. In other words, it is not sufficient (*at least!*) for them to perform only their role, simply because their own existence is the ultimate independent value for themselves, but because they affect various super-systems. Contemporary technology does not have many of the features that we find in life, but still there is something in common which gives us hope for merging (table 1, 2) the two domains harmoniously within some synthetic disciplines (e.g., in biomimetics). Our future depends on how we manage to adapt current technology to the dramatically changing environment and to help the biosphere include our civilization into its cycles. We suggest that our future ideal technology will possess all the advantages of animate nature together with our current traditional technological artifacts.

One of the basic features of living systems is the emerging of autonomy or independence of action, with a degree of unexpectedness directly related to the complexity of the living system. This gives living systems great adaptability and versatility, but on the other hand makes its behaviour difficult to predict. K. Loretz often gives this example to describe the differences of living creatures and inanimate nature: if we take a stick and hit the ball we can predict where the ball will land with high probability, but if we hit with the same stick a dog, the outcome is extremely variable and depends on numerous factors that affect dog's decision how to react (run away, bite, scream, hide, freeze, etc) On the other hand engineers in general do not appreciate unpredictability in technical systems; indeed they try to avoid it by any means. But we need to consider this even in our current technology, since nearly every technical system is actually a combination of a technical device and a human that operates it. This viewpoint immediately suggests a broader and more general definition of the very term – "a technical system" – a biological system, part of the functions of which is delegated to a device that is mostly artificial and/or non-living. This consideration is commonly omitted; technical systems are often considered in isolation, neglecting any broader context despite the fact that engineering is really a subset of human behaviour: a d*ecision making process is very common in animate nature, even amoebas make choices. In fact, it is compulsory parameter in looking for the difference between animate and inanimate object.*

At best, neglecting of the biological aspects of engineering can lead to reduced effectiveness; at worst it can produce technological catastrophes. So, there is a good reason to learn from biology how nature deals with extreme complexity and uncertainty.

	Ideal technical system	"Ideal" Biological system	Ideal future technology
1	Simple structure	Complex structure	Simple
2	Everlasting or have necessary life length	Mortal	Everlasting
3	Easy to operate (Deterministic)	Difficult external operation (due to stochastics)	Easy to operate
4	Min. use of resources	Max. use of resources	Minimal use of resources
5	Min. waste production	Min. waste production	Minimum waste production
6	Max capacity reserve	Available in abundance	Max capacity reserve
7	Easy to repair	Sustainable	Self-repairing
9	Has different modes of operation for different environment	Adaptive	Adaptable
10	Automatic	Self-regulated	Self-regulated
11	Reliable	Reliable	Reliable

Table 1: Animate and inanimate systems: two different idealities (differences are marked grey).

NON-LIVING TECHNICAL ARTIFICIAL SYSTEMS	LIVING BIOLOGICAL NATURAL SYSTEMS
1. Operate within sufficiently wide conditions, which are beyond the limits of living creatures’ tolerance. Utilisation of high-energy electromagnetic fields, laser, radiation, extreme temperatures, and pressure is wide-spread.	1. Operate within relatively narrow conditions of temperature, pressure, chemical environment, etc. Utilisation of high-energy electromagnetic fields, radiation and low temperatures is absent.
2. Most human technologies are open-ended “cycles”, which causes most of the problems in various types of misbalance and lack of sustainability.	2. Complex living systems tend to keep balance – static (homeostasis) or dynamic (homeorhesis) due to closed cycles of energy and substance.
3. Very fast and accelerating development.	3. Relatively slow rates of evolution.
4. Short term effectiveness (“here and now at any price”)	4. Long term sustainability.
5. Slow processes are considered as shortcomings.	5. Slow processes are wide-spread.
6. Economical forces make steady shift from K- to *r*-mode in products.	6. Complex ecological systems tend to drift from *r*- (“cheap”, small, short living organisms) to K-(large, long living) mode.
7. Contemporary industrial systems are unimaginable without massive global transport flows.	7. Biological systems mostly avoid long-range transportation.
8. Evolution of technology goes from mechanisation via automatisation towards nearly total replacement of humans in the technological process.	8. Living creature mainly participates in all the processes in which it is concerned as a central figure.
11. Typically new technology substitutes the old one to maximum extent.	9. The newly evolved biological systems do not necessarily substitute the old ones, but often show the parallel existence.
12. The most common type of locomotion and manipulation: rotation.	10. The most common type of manipulation and locomotion: oscillation, reciprocation, pulsation.

Table 2: The differences between living nature and technology.

2.2 TRIZ as a bridge between nature and technology

We started to merge TRIZ with biology for the needs of biomimetics (a science that takes ideas from biology to implement them in technology) – in 2000-2002 [5], [6], [7], [8], [9]. The whole aim was to use TRIZ as a bridge between biology and engineering in order to enable us to implement natural principles in design and technology. In fact biomimetic devices should provide success in the immediate future (table 1). It was also very tempting to see whether TRIZ evolutionary trends are working in animate nature as this could make a significant contribution to evolution theory. On the other hand, the trends of biological evolution might enhance the technological one. We looked at morphology development and found that some of the trends also worked in biology [10]. Analysing the biological phenomena and the laws and regularities currently being developed within biology, we found all the 40 “inventive principles” and also 72 “solution” bio-standards (in press) in biological systems at all levels of complexity – from cell to ecosystem [11]. So, there is the first evidence that biological and technological evolutions reflect a more *general reality* and therefore look similar. Such reality is the subject for the Complexity theory study.

To enable us to compare parameters from technological and biological domains we established a logical framework based on the “mantra” – “Things do things somewhere”. This establishes six fields of operation in which all actions with any object can be executed: *Things* (**substance, structure**) – this includes hierarchically structured material, i.e. the progression sub-system – system – super-system – *do things* (requiring **energy** and **information**) – it implies also that energy needs to be regulated; *somewhere* in **space** and **time**. These six operational fields (namely – substance, structure, energy, information, space and time) re-organise and condense the TRIZ classification (Contradiction Matrix) both of the Features used to generate the Conflict statements and the Inventive Principles [12]. This generalisation is considerably more logical and easier to use than the Altshuller’s 39x39 Contradictions Matrix. Our matrix allows the inclusion of more parameters that were previously missing. Moreover, our new 6x6 matrix derived from these fields has no blank cells. This more general TRIZ matrix is also used to place the Inventive Principles of TRIZ into a new order that more closely reflects the biological route to the resolution of conflicts. We call this new matrix BioTRIZ matrix [11]. It is possible now to compare the types of solution for particular pairs of conflicts in technology and biology (table 3,4).

We have analyzed 500 biological phenomena, covering over 270 functions at least 3 times each at different levels of complexity – from cell to ecosystem. In total we have analyzed about 2500 conflicts and their resolutions in biology, sorted by levels of complexity [11]. As the result we revealed some crucial differences between biology and technology that should be discussed.

Although the problems commonly are very similar, the inventive principles that nature and technology use to solve problems are very different. In fact the similarity between the TRIZ and BioTRIZ matrices is only 0.12, where complete identity is represented by 1 (Table 3, 4). This is actually not surprising at all, because technology appeared as a response to the “imperfection” of biological systems. But then this separation tends to increase and finally leads to numerous problems such as the current ecological crisis. Thus it is the right time to look at biological systems and the ways, techniques and strategies that they employ for problem solving.

Operation fields that should be improved	Operation fields that cause problems					
	Substance	Structure	Time	Space	Energy/Field	Information/ Regulation
Substance	6, 10, 26, 27, 31, 40,	27	3, 27, 38	14, 15, 29, 40,	10, 12, 18, 19, 31	3, 15, 22, 27, 29
Structure	15	18, 26	27, 28	1, 13	19, 36	1, 23, 24
Time	3, 38	4, 28	10, 20, 38	5, 14, 30, 34	19, 35, 36, 38	22, 24, 28, 34
Space	8, 14, 15, 29, 39, 40	1, 30	4, 14	4, 5, 7, 8, 9, 14, 17	6, 8, 15, 36, 37	1, 15, 16, 17, 30
Energy/Field	8, 9, 18, 19, 31, 36, 37, 38	32	6, 19, 35, 36, 37	12,15, 19, 30, 36, 37, 38	14, 19, 21, 25 36, 37, 38	2, 19, 22
Information/ Regulation	3, 11, 22, 25, 28, 35,	30	9, 22, 25, 28, 34	1, 4, 16, 17, 39	2, 6, 19, 22, 32	2, 11, 12, 21, 22, 23, 27, 33, 34,

Table 3: Matrix derived from standard TRIZ 39x39 matrix

Operation fields that should be improved	Operation fields that cause problems					
	Substance	Structure	Time	Space	Energy/Field	Information/ Regulation
Substance	13, 31, 15, 17, 20, 40	1, 2, 3, 15, 24, 26	15, 19, 27, 29, 30	15, 31, 1, 5, 13	3, 6, 9, 25, 31, 35	3, 25, 26
Structure	1, 10, 15, 19	1, 15, 19 24, 34	1, 2, 4	10	1, 2, 4	1, 3, 4, 15, 19, 24, 25, 35
Time	1, 3, 15, 20, 25, 38	1, 2, 3, 4, 6, 15, 17, 19	2, 3, 11, 20, 26	1, 2, 3, 4, 7, 38	3, 9, 15, 20, 22, 25	1, 2, 3, 10, 19, 23
Space	3, 14, 15, 25	2, 3, 4, 5, 10, 15, 19	1, 19, 29	4, 5, 14, 17, 36	1, 3, 4, 15, 19	3, 15, 21, 24
Energy/Field	1, 3, 13, 14, 17, 25, 31	1, 3, 5, 6, 25, 35, 36, 40	3, 10, 23, 25, 35	1, 3, 4, 15, 25	3, 5, 9, 22, 25, 32, 37	1, 3, 4, 15, 16, 25
Information/ Regulation	1, 6, 22	1, 3, 6, 18, 22, 24, 32, 34, 40	2, 3, 9, 17, 22	3, 20, 22, 25, 33	1, 3, 6, 22, 32	3, 10, 16, 23, 25

Table 4: BioTRIZ matrix derived from biological effects

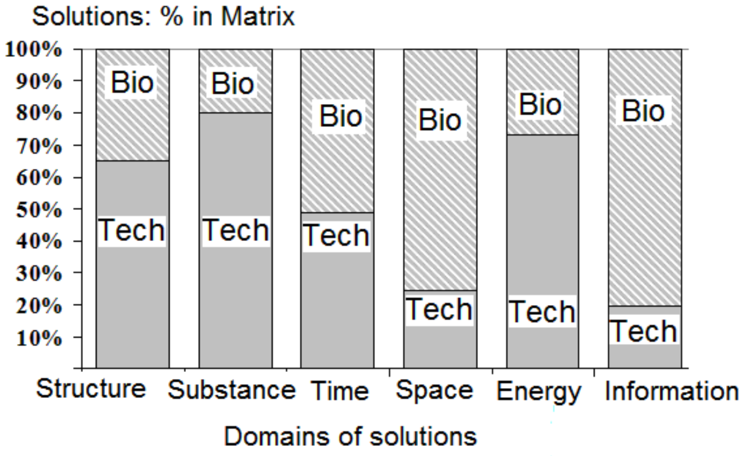

Figure 1: Biology and engineering: a comparison of TRIZ and BioTRIZ contradiction matrices.

As it is clear now that bio- and technological “design” have almost completely opposite strategies, we may even regard them as two anti-systems. Technology tends to solve problems spending energy and building up structures, changing substances – in energy and matter domains. In animate nature problems are mostly avoided in space and resolved in information – this is much cleverer and less energy demanding way of problem resolution (Figure 1). There is obvious challenge for synthesis. To develop the approach to such a synthesis we need to know the reasons for this kind of difference.

We may find the answer while comparing the evolution trends in life and technology.

3 TWO “EVOLUTIONS”

Evolution is one of the most exciting subjects as everyone is interested why this world is changing and why some changes lead to success, but other changes cause failure and extinction. It is vital for us to understand the principles that underline these changes. After G. Altshuller’s discoveries of mechanisms and trends in evolution of technology, many papers were published to support and to enhance these ideas. Nearly all TRIZ specialists contributed to this subject. The recent book of Nikolay Shpakovsky “Trees of evolution” [13] is the best and the most exhaustive one, which also has a review of different opinions and recent achievements.

3.1 What are we studying?

Let us firstly define what we mean by the word “evolution”. Evolutions of species, evolution of societies, and evolution of aeroplanes have certainly different meanings and express different processes. The word “evolution” has a “tail” context taken from biology – transformation of species and origin of new ones as a result of numerous natural mechanisms of selection. Technology evolves more as behaviour does (rather than physiology and morphology) as it is the product of innovation and problem solving. Also it is driven by human minds and decision making in particular. Without humans all our clever devices are purposeless. In this sense the evolution of technology in fact reflects how our mind works. Being driven by human minds we can regard technological evolution as to a large extent a subjective phenomena.

The most discussed aspect of biological evolution is the evolution of morphology (which is not mind-driven). Of course there are some fruitful hypotheses on behavioural evolution, but within the current evolutionary paradigm they can only deal with genetically inherited patterns of behaviour. Therefore the decision making process is totally excluded from the evolutionary concepts in biology. According to current views biological evolution is not driven by mind and therefore can be certainly regarded as an objective phenomenon.

The laws of evolution formulated in TRIZ (the law of system completeness, energy conductivity, rhythm coordination, increase of ideality, uneven development of system parts, dynamisation, etc.) are not **laws** *s.str.,* but trends or tendencies. They describe the process, but not the very mechanisms of it. When we are building “evolutionary” trees we in fact applying these trends to generate product diversity and to get “lines” of evolution. The only mechanism of technological evolution is that it is driven by resolutions of contradictions. It is hard to distinguish the borders and causality amongst TRIZ “laws”, “trends” and “lines” in the real life, so for our convenience we have put them all together into one table (table 5).

There is also difficulty in revealing the mechanisms that drive biological evolution. They are different for macro-evolution (evolution of high-range taxons and ecosystems) and micro-evolution (evolution of species). These mechanisms are also different on molecular level (genes) and on the ecosystem level. Moreover there are more than 24 different concepts about these mechanisms that drive the evolutionary process in living nature [14]. In spite of the fact that there is enormous amount of literature on modelling of the evolutionary process, we still know very little about *actual* mechanisms of evolution: computer models (or better to say – simulations) of evolution process currently do not give reliable predictions, they express the human *opinions* on the reality rather than reality itself and often unfortunately are not properly substantiated and validated by evolutionary biologists and are yet to be used in industry. The only exclusion is so called Evolutionary optimisation algorithms, which were developed from the **inspiration** of the works on genome evolution and had nothing to do with the real evolution of species and eco-systems at all. As we decided to deal with real and “solid” facts (visible results of evolution) we excluded from our consideration the vast amount of literature on modelling of different hypotheses of evolutionary process.

So, we intentionally limited ourselves and assumed that we can neglect the mechanisms/causes which drive evolution in technology and biology as they are obviously different for animate nature and technology. We are dealing only with the results of those mechanisms in action – with trends we can observe as scientific fact (not an opinion). We operate with well known facts described in the books on comparative anatomy and physiology, evolutionary morphology, ecology (cycles of energy and substance in different eco-systems and within different time scale), palaeontology, etc. For our assumptions we used the knowledge that general biology accumulated for the last 200 years [15]. [16], [17], [18], [19], [20], [21], [22], [23, [24] and many other publications In the current paper we as experts provide ‘compressed information’, which has not been trivial to extract from numerous case studies on comparative anatomy, physiology and evolutionary morphology.

So, in our discussion of the evolution trends we are leaving for the future the questions “how?” and “why?”, but answering only “what?” or “how it looks like?” questions.

3.2 New evolution trends for future technology

Both of the realms – biology and technology – have profound intrinsic advantages and shortcomings. The challenge for future engineering and TRIZ as decision-support tool is to use positive sides and get rid of shortcomings of the both domains. In such case we will achieve the ideal result for future technology (table1). We analysed the evolution trends in technology and biology. The comparisons of biological and technological systems are presented in the table 3. From the total amount of sixteen trends (table 5) only four are common for technology and living systems, three biological trends happened to be unknown within technology, two technological ones are not described in biology and seven trends are opposite for biology and technology. Such as, for example to achieve sustainability all technological processes should follow the “steps” of long-term bio-evolutionary strategies and middle-term ecological cycles (e.g., ecological successions); increase the energy flow paths, provide enough diversity for complex engineering systems or networks to achieve reliability, etc (table 5).

It is very clear that the vectors of development of animate nature and technology are opposite. In some cases, when we need to conquer nature, this gives local advantages, in others (or sometimes at the same time), if we want to cooperate with nature creates problems as current engineering strategies evolved to replace natural phenomenon rather than use it. If engineering eager to evolve towards nature, technology has now at least ten new strategic lines to follow to prepare it for future market conditions.

Trends in technical evolution	Trends in biological evolution
1. Transition of the working functions from the macro- to the micro-level	
2. Increase of the degree of ideality – the more emptiness in a system the better.	
3. Systems change while they grow following S-curves	3. System ontogenesis can be expressed in S-curve
4. Systems and products evolve toward the use of higher frequency energy and use of fields: Gravitational - Mechanical – Acoustic – Chemical – Thermal - Magnetic - Electric - Electromagnetic	4. Life started as a bio-chemical phenomenon and evolved towards the active search for energy resources. Single-cellular organisms started from: Electro-Magnetic – Electrical- Chemical – Mechanical (multi-cellular organisms)- Acoustic (complex communication) in their organisation and behaviour.
5. Dynamisation, **increase** of the degree of freedom and flexibility.	5. **Decrease** of the degree of freedom in functions – species specialisation. The more primitive biological taxons are the more their universality.
6. Mono-Bi-Poly cycles , i.e. **polymerisation** of **monomerical** parts.	6. Trends in the evolution of morphology: **oligomerisation** of effectors and **metamerical** parts of the body.
7. Segmentation: **reduction** of the unit.	7. Replication, reproducing, cloning, metamerisation: **multiplication** of the units
8. **Increase** of automation and eventual exclusion of humans.	8. Increase of the role of the central control and sophistication of the nervous system. But decrease of automation, increase the role of feed-forward control.
9. “Folding-Unfolding” structural complexity.	9. Morphological degradation of parasites and other super-specialised species (“folding”) is the dead-end of the evolutionary line.
10. Harmonization and coordination of the system parts (materials, shape, structure, information, rhythms and energy distribution)	10. Also true for all living systems
11. Parts of systems (sub-systems) evolve non-uniformly, creating constantly changing opportunities for innovation.	11. Species either change themselves or change each other. Misbalance in sub-systems’ interactions causes ecosystem catastrophes or individual physiological stress, illness and triggers changes or death.
12. Shortening of the Energy Flow Path.	12. Energy flow paths are getting longer in the evolution of life on our planet
	13. The acceleration of evolution speed is in direct proportion to the complexity of a system (mammals evolved faster than bacteria).
14. Life span of a product is definitely shorter than the life spans of the classes of similar product and obviously shorter than the life of the whole industrial branch.	14. Life span of the ecosystem is 4-5 time larger than life spans of families, the families live 3-4 times longer than genus, genus – 3-4 time longer than species.
	15. The higher level of system complexity the more diversity of forms of such systems. Eukaryotes more complex than prokaryotes and contain 500 times more different species.
	16. Living nature evolves from short life-cycles to the long life-cycles. For example, the cycle “phototrophs →reducers→mineral substances→ phototrophs”” evolves to the cycle “phototrophs (producers) → consumers-1→consumers 2→…..→ reducers→ mineral substances →phototrophs””

Table 5: The differences and similarities (grey) between the evolution trends in animate nature and evolution of technology.

4 SUMMARY

In the TRIZ literature the expression of “evolution of technical/technological systems” is widely accepted and employed. This is OK until the technology is compared with biology, where the same term is in circulation more than 200 years. Borrowing biological principles for the engineering applications causes serious confusion and misunderstanding of the concept of evolution. Biological systems possess at least two more types of transformation (ontogenesis and ecological succession) and they are different from evolution *s.str.* That is why the work we’ve done on comparison and analysis of transformations and development in biology and technology is essential.

Engineers mostly consider the future; biologists are mostly focused on the past. Both approaches have their own advantages. Living creatures both adapt themselves to the environment and change the environment for their needs. But these two processes are very well balanced in nature. This is not true for the technology: we put too mush pressure on the environment and very little adapt to the needs of natural environment. So, there are two evolution strategies – adapt *to* environment and adapt *the* environment. If unbalanced these strategies become dangerously separated as their driving mechanisms do not match each other. We could make a long list examples of contradictions life and technology, but we only pointed out the main issues. Some of the technologies already realised the danger of the growing gap and already start making attempts to improve this opposition. For example, the founders of permaculture tried to formulate the new approaches in agriculture and related spheres [25].

Technology should learn a lot how to be adapted to the environment. Now it is obvious that we should merge both the most advanced features from biological principles and the vast historical engineering experience [10].

In our research we found the similarity of design patterns (inventive principles), but not the context of their application within the evolution trends of life and technology [11]. [26]. This means that evolution of animate nature and evolution of technology are different phenomena as a result of their original aim – to change the environment or to change themselves. The future of technology also must lie in its ability to deal with its own complexity and ability to build itself into the life of biosphere. Knowing natural principles that we learnt from biology may contribute significantly to the future of technology as this knowledge underpins the laws of any complex system development.

As the result of our study, future industry now has at least ten new strategic lines to follow to prepare itself for future market conditions. Our BioTRIZ tool [11] was developed to initiate this process. Taking into account the laws of development (not only evolution in biological sense!) of living and non-living artificial systems within one engineering domain is the real challenge! Modifying TRIZ into its Bio-TRIZ version hopefully makes technology more ecologically sound and environmentally friendly and therefore sustainable. When we carry out problem-solving workshops we give our customers option to use classical TRIZ contradiction matrix and the biological one and nearly all participants have found their best solutions using the inspiration from the BioTRIZ matrix. This does not mean that we have developed something better than Altshuller. It only shows that current market demands shape technology in such a way that it should co-evolve with life and follow evolution trends of living systems in order to survive.

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6 REFERENCES

[1]. Altshuller G. S., 1973, Algorithm of invention. Moscow, “Moscow worker”.

[2]. Altshuller G.S., Rubin M., 1991, What will happen after the ultimate victory of technology? Chance for Adventure, Petrozavodsk: 221-237

[3]. Bowyer, 2007, Breed your own Design, Icon Magazine, 52.

[4]. Zykov V,, Mytilinaios E., Desnoyer, M., Lipson H., 2007, Evolved and Designed Self-Reproducing Modular Robotics, IEEE Transactions on Robotics, 23: 541-546.

[5]. Bogatyreva O. A., Vincent J.F.V., 2003, Is TRIZ Darwinian? TRIZCON-2003, , Altshuller Institute, USA. 16-18 March: 17/1-17/5.

[6]. Bogatyrev N.R., 2000, Ecological engineering of survival, Publishing house of SB RAS, Novosibirsk.

[7]. Bogatyrev N.R., 2004, A “living” machine. Journal of Bionic Engineering, 1, 2: 79-87.

[8]. Bogatyreva O.A., Pahl A.-K., Bogatyrev N.R., Vincent J.F.V., 2004, Means, advantages and limits of merging biology with technology. – Journal of Bionic Engineering, 1, 2: 121-132.

[9]. Vincent J.F.V., 2002, Smart biomimetic TRIZ, TRIZ Future, ETRIA World Conference, Strasbourg: 61-68.

[10]. Bogatyrev N.R., Bogatyreva O.A., 2003, TRIZ and biology: rules and restrictions, Proc. Of International TRIZ Conference, Philadelphia, USA, 19: 1- 4.

[11]. Vincent J.F.V., Bogatyreva O.A., Bogatyrev N.R., Bowyer A., Pahl A.-K., 2006, Biomimetics – its practice and theory. “Interface” Journal of Royal Society, 3, 9: 471-482.

[12]. Bogatyreva O, Shillerov A, Bogatyrev N., 2004, Patterns in TRIZ Contradiction Matrix: integrated and distributed systems, 4-th ETRIA Conference, Florence, 3-5 November: 305-313.

[13]. Shpakovskii N., 2006, Trees of Evolution, Puls, Moscow.

[14]. Bogatyreva O.A., 1991, The Concept of social succession Nauka, Novosibirsk.

[15]. Berg, L.S., 1958, System der rezenten und fossilen Fischartigen und Fische. VEB Verlag der Wissenschaften, Berlin.

[16]. Berg L.S. Study of Evolution Theory, 1977, Nauka, Moscow.

[17]. Chaikovskii Yu.V., 2003, Evolution, Centre for system research, Moscow.

[18]. Beklemishev V.N. 1964, Foundations of comparative anatomy of invertebrates. Nauka, Moscow: I & II.

[19]. Foster A.S., Gifford E.M. ,1959, Comparative morphology of vascular plants, San Francisco, Freeman and Co.

[20]. Thompson d’Arcy W., 1959, On Growth and form, Cambridge, Cambridge University Press: I & II.

[21]. Snodgrass R.E., 1935, Principles of insect morphology, McGraw-Hill Company, New York, London.

[22]. Imms A.D., 1960, A general text book of entomology including the anatomy, physiology, development and classification of insects, London, Methuen & Co Ltd.

[23]. Kardong K. V., 2005, Vertebrates: Comparative Anatomy, Function, Evolution, McGraw-Hill Science Engineering.

[24]. Greger R., 1988, Advances in comparative and environmental physiology, Springer-Verlag Berlin; London.

[25]. Mollison B., Holmgren D., 1978, Permaculture one. A Perennial Agriculture for Human Settlements, Tagari Publications, NSW 2484.

[26]. Pahl A.-K., Vincent J.F.V., 2002, Using TRIZ-based Evolution Trends to integrate Biology with Engineering Design, TRIZCon, St. Louis, USA.