Altshuller's laws of technical systems evolution as productive tautologies

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1 Goal and structure of the paper

In 1979, Genrich Altshuller published 8 laws of technical systems evolution [1], which according to him [2] can be found by systematic study of high quality patents. Both, critics [3] and advocates [4] of the usefulness of Altshuller's laws emphasize that thousands of patents were analyzed to discover these laws. Although there is an abundant literature proposing divergent formulations of these and other laws that are often called *trends* or *patterns* (see, for example, [5-10]), we will concentrate on Altshuller's initial formulation from 1979 [1].

Our paper aims to show that not a single patent must be studied in order to arrive at Altshuller's eight laws of technical system evolution. Rather, they follow from the meaning of *technical system* — or more precisely *development of artificial instrumental systems in a world with scarce resources*. This is the only reason why they might be able to lay claim to some law-like status — at least as long as the respective conditions for their application are respected.

The paper comprises three major parts. First, we will articulate in general terms what systems are by putting our focus on the notion of *instrumental systems*, which can either be *static* or *dynamic*, and *natural* or *artificial* (chapter 2). Second, we will show that Altshuller's eight laws from 1979 can be inferred from the general statements explaining these distinctions — at least insofar as additional restrictions such as *scarcity of resources* and *competition* are assumed (chapter 3). Third, we will reflect on the status of Altshuller's laws, showing why their modified versions can be viewed as productive tautologies and point the way to how more of these tautologies could be derived (conclusions 4).

2 General reflection on systems
2.1 Systems in general and instrumental systems in particular

A system is a whole that consists of parts. Together these parts bring about effects. Systems are useful as long as they can be *controlled* such that their ability to realize effects makes it possible to

employ them for particular purposes in particular contexts. When systems are employed for particular purposes, they are serving functions and will be called *instrumental*.

2.2 Living systems with needs and desires

Living systems depend on instrumentalizing their environments. They must build cellular components from chemicals and energy (anabolism) and break down organic matter (catabolism) to either release energy or to serve anabolic reactions. These processes of metabolism require living systems to make use of what their environments provide. We will call a lack that would threaten a living system's healthy existence — if not satisfied — a *need*. In addition to needs, some living systems — in particular humans — have *desires*. They come as the feeling of wanting.

2.3 Satisfaction of needs and desires requires activity

In order to fulfill a desire or to satisfy some need, living systems must do something. Humans, for example, must breathe to enrich themselves with oxygen and plants must convert sunlight into chemical energy for growing. While — for most people — breathing is a subconscious activity most of the time, putting ourselves under water changes the situation entirely. Our standard technique of enriching our blood with oxygen won't work anymore.

2.4 Solving problems with techniques and technical devices

Living systems face problems, as soon as they are unable to fulfill some desire or to satisfy some need. Problems can be solved in a variety of ways. What can count as the most appropriate solution depends on context. Sometimes simple techniques such as breath retention can do the job. Sometimes, a basic technique is not enough, and some external enhancement is needed, for example a snorkel that allows us to breathe under water as long as the opening at the top of the snorkel remains above the waterline. In the latter case, we have employed something to help us satisfy our need to enrich our blood with oxygen by enabling us to breathe. We are not only using some technique but also some technical device.

2.5 Artificial and natural systems

While strolling around, we could be lucky and find some specially grown hollow wooden tree limb and use it is as a snorkel. Alternatively, we could make one on our own. In the first case, we would have to be able to recognize the *function* that the wooden limb could perform for us. In the second

case, we will have to purposefully process something such that it can serve this function. In both cases, we must be able to recognize our need and understand that we are looking for something that makes it possible for us to breathe under water. It might already exist and we have to find it, or it might not exist yet and we must create it. We will call everything that was purposefully created *artificial* to distinguish it from *natural* things that were not purposefully put together by someone.[1]

2.6 Functional parts

In its simplest version, a snorkel is a hollow stick that is U-shaped at the bottom. The shorter leg fits into a human's mouth, while the longer leg is straight and reaches out of the water when used as a snorkel. Although the device consists of only one part, it can be called a system, because from a functional perspective, multiple parts can be distinguished: the "mouth part", the "channel part", and the "chimney part".

2.7 Energy transformation and activity or static systems vs. dynamic systems

Active systems spend their own energy and can be called *dynamic*, while *passive* systems don't spend energy and can be called *static*. As a consequence, static systems cannot produce effects on their own, but rely on active systems to do so. The snorkel from the above example is passive, while its user is active. Since energy cannot be produced from nothing, active systems have to be their own energy source by somehow transforming energy from their environment. *Energy transformation*, therefore, is a key feature of dynamic systems.

2.8 The functions of systems show in the respective dynamic super-systems

Due to their dependence on dynamic systems, we would not be able to identify a static system's function if we were not able to imagine or observe it performing its roles within dynamic super-systems.[2] For example, a bicycle on its own is a static system. When being ridden, it is part of a dynamic super-system within which it serves a function. A bike has the disposition to become dynamic, but it is not dynamic in itself. The same holds for the snorkel. Only when used by someone for snorkeling does this static system become part of a dynamic super-system and show its proper function. Viruses show the same pattern. As isolated particles, they are static systems, but in conjunction with cells they form reproductive dynamic super-systems. In one sentence: to

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[1] The totality of roles that an artificial system can be employed for does not have to be equal to the set of roles it was designed for in the first place. A bridge, for example, can be designed for allowing cars to cross a river, but it might also provide shelter from rain.

[2] Note that some of the functions responsible for keeping the static system's form can be identified irrespective of the system's role in dynamic super-systems.

understand functions of systems, we have to investigate them in the context of the dynamic super-systems they belong to.

2.9 Hierarchical system structure

Dynamic super-systems can themselves be systems in some wider dynamic super-system. A cyclist on a treadmill, for example, can be part of an energy generating fitness center. The treadmill (static system) and the cyclist (dynamic system) form a dynamic super-system, which is part of the larger dynamic super-super-system that consists of multiple ridden treadmills, a battery etc. Most of the time, systems exist in much more complex hierarchies than this one and it would be pointless to add the prefix "super" to each higher or "sub" to each lower level. From now on, we will therefore abandon this practice if no additional clarity can be gained by pointing out the different levels of hierarchy.

2.10 Energy input as a key feature of dynamic systems

Although the ridden treadmill transforms mechanical energy into electrical energy, it is a static system because it requires a cyclist to receive energy in the first place. Therefore, the ability to transform energy is not enough for a system to be dynamic. Suppose the cyclist was replaced by a combustion engine providing the mechanical energy needed to turn the shaft of the pedals. As long as they are being fueled, engine (dynamic) and treadmill (static) would become a dynamic system. *Energy input* is thus a further key feature of dynamic systems. A dynamic system that is cut off from its energy source will sooner or later turn into a static system.

2.11 Dependence versus relative independence

If a dynamic system does not have control over its own energy input, it is dependent on the dynamic system controlling it. This dependency comes in different forms. Electronic devices have power switches that are controlled by their users, solar thermal heating systems depend on whether or not the sun is shining and mammals have to find food or water to fuel their metabolism. Roughly speaking, the dynamic system controlling another's energy input determines whether or not the latter will remain dynamic or become static. Generally speaking, the more control a dynamic system gains over its fundamental operational functions such as energy input, the more independent it becomes.

2.12 Energy conduction, control, and work as key features of dynamic systems

As far as we know, energy can neither be destroyed nor created, but only transformed from one form to another. That dynamic systems transform energy shows in their production of effects. Some of these effects might be useful for someone while others might not. This usefulness of the produced effects is the result of their work and it is also the reason why they are employed by others for their purposes. However, the work a dynamic system is employed for is different from the work carried out by the dynamic system's mechanism. When we want to turn a shaft by means of a combustion engine, the engine must burn fuel to transform chemical energy into mechanical energy. Besides guiding the input energy to its place of conversion and transforming it, the energy must be directed to where it can do the work it is supposed to do. Directing energy requires both control over the energy flow and the capacity to conduct energy from input, via transformation, to output.

2.13 Scarcity of resources and efficiency

Those who employ a static or dynamic system for their own purposes are interested in the output produced by the dynamic super-system emerging during this process. The output shows in the work being done. This work comes at some cost. It is tempting to say that a dynamic super-system that consumes less energy to produce the same amount of work under similar conditions and with more or less the same undesired side effects is better than a system that consumes more. However this only holds if the energy resource we are talking about is scarce or at least hard to obtain. C4-plants, for example, concentrate higher amounts of CO_2 in their leaves than C3-plants, which allows for an increase of sugar production in conditions of high light and temperatures, but given the abundance of sunlight and CO_2, both types of plants are doing just fine. In contrast, that modern societies are carelessly burning through the Earth's scarce fossil fuel resources is based on the delusion of their abundance. In general, systems that require fewer resources — *i.e.* input energy of a certain type, material of a certain type, time, and space — for doing the same amount of work without compromising quality are more efficient than those that require more.

2.14 From efficiency to ideality

Assuming scarcity of resources, the value judgment can be made that a system is more ideal when it is more efficient (compared to a system of the same kind). Higher efficiency results in competitive advantage over less efficient systems. Under the pressure of competition, systems evolve towards being more efficient and thus more ideal. Idealizing the efficiency equation by zeroing the amount

of resources needed to execute a system's function results in Altshuller's famous definition of ideality: *The ideal system is the fulfillment of the function without a system* [11].

2.15 Integration in wider super-systems

From the tendency to develop towards higher efficiency, a trend toward functional integration into larger super-systems can be inferred: (i) A system that is serving multiple functions is more ideal than (ii) multiple systems that are serving all of these functions individually, assuming that (i) consumes fewer resources (space, time, energy, materials) and (ii) that the quality of the execution of the functions is not compromised by the integration.

2.16 Integration means mediating conflicts

Functional integration yields conflicts insofar as systems that are to be integrated compete over shared resources (space, time, material resources, energy). Systems that are able to integrate their sub-systems in a win-win fashion will be more competitive, *i.e.* efficient, *i.e.* ideal than those that cap the potential of their individual sub-systems due to inner-systemic conflicts.

2.17 Increase of efficiency through increase of control over more fundamental activities

When taking a look at the energy flow in dynamic systems above, we came across (i) energy input, (ii) energy transformation, (iii) energy conduction, (iv) energy control and (v) targeted energy output as necessary functions. The efficiency of each of these functions contributes to the system's overall efficiency. Loss of energy during any of these activities diminishes the overall efficiency and therefore provides opportunities for increasing ideality through problem solving. Since energy cannot get lost, *loss of energy* refers to transformation of energy into a form that cannot be used for executing the system's functions and, in this sense, is wasted. The better a dynamic system controls the activities underlying these functions, the more it will get out from its initial energy input.[3]

  The idea behind this principle is simple: intervening closer to where an activity originates allows for more controlled guidance of resulting effects as compared to intervention on the level of

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[3] How efficiently energy can be transformed by a given system depends on its ability to release the energy that is stored in what the system takes as input. Given that the maximal energy of a body is equivalent to its mass, a dynamic system can operate with increasing amounts of energy, the more control it gains over the matter it is dealing with. Burning a kilogram of dry straw provides approximately 16.8 MJ in energy. The loss of rest mass of about 1.9×10^{-7} g is so small that it is nearly impossible to measure. In contrast, when uranium decays, 0.1% of its mass is released as energy. After the reaction, the mass of the substance that initially was one kilogram of uranium is about one gram smaller, which is equivalent to a release of 9×10^7 MJ. To use uranium as an energy source, we must be able to trigger the required chain reactions and control them adequately, which requires understanding and control of the processes on an atomic scale. In contrast, in order to burn and control one kilogram of straw, all we have to know is how to initiate and sustain a fire, which can be done on a macro-scale level. If we were able to transform the entire kilogram of anything's rest mass into energy, we would obtain roughly 9×10^9 MJ. To do so we would have to be able to control the building blocks of matter on the lowest scale possible.

later emerging effects. For example, a central bank that aims at increasing investments into the economy by lowering interest rates cannot determine what banks will do with the cheap money. In contrast, direct control of the decision making of the banks would allow for more targeted intervention. The same holds for effects emerging from the activities of objects on an atomic and sub-atomic scale such as electromagnetism or material properties. The better we understand and control the origin of the effects of interest, the better we will control the effects themselves. Since increasing ideality is achieved by reducing losses while increasing functionality, systems that efficiently control the effects they exploit on the most fundamental level of their emergence, will turn out to be more ideal than systems operating at a later stage in the chain, where losses have already accumulated. If the origin of the effects exploited by some system resides at the sub-atomic scale, the system will have to obtain better control over the lower-scopic[4] levels to increase its efficiency and become more ideal. As more refined physical cause-effect relationships become known for further exploitation, we will see an increase in systems using them for their purposes. This holds for both the creation of artificial instrumental systems and for our understanding of the causal mechanisms operating in natural dynamic systems.

3 Inferring Altshuller's eight laws of technical systems development

This general understanding of systems is sufficient to derive Altshuller's eight laws as stated in 1979 [1]. Altshuller split them into three groups: A) statics, B) kinematics, and C) dynamics. Note that Altshuller's usage of the terms "statics" and "dynamics" differs from our usage.

A) The first class of laws deals with the beginning of a technical system's life, which is understood as the result of synthesizing parts into a whole.

1) The first law states that a technical system would not be able to perform its functions, unless at least the following four parts with their respective functions are present: engine (for energy conversion), transmission, working unit and control unit. At least one of these parts must be manageable to make the system manageable.

As we have seen, this statement only holds for dynamic systems. Static systems, such as tables, picture frames, plates, chairs, unridden bicycles, etc. do not have to transform energy in any

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4 We avoid the term "microscopic" since "micro" has the well-defined meaning of 10^{-6}. By coining the term lower-scopic, we want to convey the meaning of a spectrum for zooming out (macro-scale) and zooming in (towards sub-atomic scale).

meaningful manner in order to provide their functions.[5] The need for the five functions — (i) energy input, (ii) transformation, (iii) transmission, (iv) control and (v) targeted output (working unit in Altshuller's sense) follows from the fact that dynamic systems have to convert and control energy to bring about the effect that makes them instrumental for something (instrumental systems), themselves (self-sustaining living systems) or both (see 2.7, 2.10, and 2.12).

2) Altshuller's second law states that a system's need for energy transformation requires the ability to conduct energy from the conversion unit to the working body. As we have seen, this can only be said about dynamic not static systems and is already contained in the meaning of *transmission/conduction* (see 2.12).

3) The third law states that all parts of the system should work in coordinated rhythm.

Again, this only holds for dynamic systems and is due to the requirement that multiple parts have to contribute to the same process, which is the production of the system's effects through energy conversion and control. Insofar as the parts contribute to the same process their contribution has to be coordinated in time, which is just a different way of saying that coordination of rhythm is required.

B) Altshuller put the second set of laws under the title "kinematics" stating that they refer to the development of technical systems irrespective of specific technical or physical factors contributing to the development.

4) Altshuller's fourth law is probably the most popular one and claims that all technical systems develop towards an increasing degree of ideality with the system's weight, volume and area tending towards zero, without diminishing its capacity to perform work, resulting in Altshuller's popular definition of an ideal technical system as function without a system [11]. In the TRIZ literature, it is common practice to understand ideality not only in terms of spatial and material resources, but also in terms of all resources (time, space, energy input, material resources) in the form of a qualitative cost-benefit equation with functionality above and costs and problems below the fraction line [12].

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[5] When zooming onto an atomic and sub-atomic level, we will find dynamic energy conversion, irrespective of whether we are analyzing a static or a dynamic system. However, this doesn't affect the meaning of the distinction between static and dynamic on a macro-level.

In [5], which is a translation of [13], ideality is defined as the ratio between useful and harmful effects.[6]

As seen above, the trend of increasing ideality is due the need to increase efficiency. Increased efficiency, in return, provides a competitive advantage when resources are scarce. While the law of increasing ideality refers to both static and dynamic systems, it depends upon the assumption of competition and scarcity of resources. It would be an interesting thought experiment to investigate what would happen to the trend towards an increasing degree of ideality if the problem of scarcity of resources were solved.

5) The fifth law states that the parts of a technical system develop unevenly. As a consequence, system conflicts arise, where one sub-system hinders the further development of another. Altshuller's example here is the insufficiency of brake systems in large ships [15].

This argument depends on two assumptions. The first is the system definition itself stating that systems bring about their effects by collaborative work of their parts. Due to the dependency of systemic effects on the interaction of all of the relevant parts of a given system, weaker parts will be bottlenecks for the stronger ones or the system will become unstable when weaker parts cannot balance out the stronger. The second assumption, which is not contained in the system definition itself, is that these parts do not develop simultaneously. This might be true if the system's designer was unilaterally focused. However, the law will collapse as soon as systems are developed from a holistic perspective by taking the functions of all sub-systems into account.

As we have seen above, there is another argument for the necessity of the outbreak of system conflicts that doesn't rely on assuming a limited perspective of the designer (see 2.16). Rather, it is based on resource dependency. Different sub-systems might exploit shared resources (energy, material, time and space), which will result in conflicts when these resources are scarce.

6) Altshuller's sixth law states that when systems have exhausted their developmental potential, they become sub-systems within larger systems — that is their function is integrated into a super-system. As we have seen, this follows from the ideality statement under the condition that the function of the integrated systems is enhanced rather than worsened and that the non-integrated individual systems would require more resources for delivering their function (see 2.15).

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[6] According to [14], the translation contains slight modifications, but we currently have no access to [13] to judge whether or not they affect this definition of ideality.

C) The third class of Altshuller's laws is titled "dynamics" and reflects the main trends in the development of technical systems in our — or rather Altshuller's — time; *Creativity as an Exact Science* was published in 1979 [1].

7) The seventh of Altshuller's laws claims that when a system's developmental potential is exhausted on the macro level, it will be fundamentally rebuilt with its working body acting on a lower-scopic level. As we have seen, this is due to the principle that the ability to control the more fundamental activities from where the effects emerge provides more control over the entire process. Therefore, less energy loss is accumulated, which results in higher efficiency and thus a higher degree of ideality. Moreover, the production of new effects is made available (see 2.17).

8) The eighth of Altshuller's laws finally states that the development of technical systems proceeds towards an increasing involvement of substance-field systems. In order to clarify the meaning of this statement, we first need to look at the role that substance-field (Su-Field) systems play in Altshuller's theory. Roughly, the Su-Field notation aims at representing problems in terms of cause-effect relationships by means of three major categories: *substances*, *fields* and *actions*. Fields are supposed to act upon and to be produced by substances. The actions of *being produced* and *acting upon something* are represented by means of arrows, which can highlight qualitative differences (harmful, useful, insufficient, and excessive). This notation is used to represent problems and can be converted into the notation of functional modeling where components (substances) act via functions (arrows) upon other components. The main difference between *function* and *field* seems to concern the level of abstraction. While fields are categories for physical effects, functions describe the activity by which one component acts upon another. In order to preserve the information represented in a Su-Field model which states that "A pushes B" by means of a mechanical field, we would have to say "A mechanically pushes B". Thus, in a Su-Field representation, the physical principles bringing about some effect are made explicit (something that is not necessarily shown in a functional diagram, but could easily be added).

Altshuller's eighth law states that no-field systems tend to develop into field systems (note that Altshuller's notion of a *no-field system* might be equivalent to what we are calling *static system*), the number of connections between the elements of a system increases, the responsiveness of the system increases, and mechanical mechanisms are replaced by electromagnetic ones.

All of these observations result from statements outlined before, namely that (i) the ability to efficiently control lower-scopic effects often makes it possible to influence matter more efficiently and extensively than handling them on a macroscopic mechanical scale (see 2.17) and that (ii) static systems are only useful insofar as they are integrated into dynamic super-systems (which refers to no-field systems turning into Su-Field systems) (see 2.7 and 2.8). Note that (i) is only true if we can control the lower-scopic behavior efficiently enough to gain an advantage over macroscopic mechanical control.

4 Conclusion

We have shown that, without the study of a single patent, Altshuller's eight laws of technical system development from 1979 [1] can be derived from a reflection on the nature of systems, in general, and instrumental systems in particular. It could be shown that these statements are general enough to be formulated for both artificial and natural systems. Moreover, we drew the attention to *resource scarcity* as a fundamental condition for the validity of most of these laws. Given that the number of general resource types is limited — time, space, material, energy — we believe that additional general statements about systems can be derived by further taking into account the general characteristics of each resource type. Doing so might result in the formulation of trends similar to the patterns articulated in [16]. The same holds for (i) a more thorough investigation of the 5 fundamental functions of dynamic systems, (ii) a closer look at differences of employing living or non-living systems for certain jobs, and (iii) a definition by cases depending on the instrumental system being abstract (theories) or concrete (material).

All in all, this shows that the law-like nature of these general statements about systems is due to their inferability from even more general statements. Consequently, it can be said that we are dealing with tautologies, where the conclusion is implied by the meaning of the term in the premise. For example, a bachelor is an unmarried man. By saying "he is a bachelor, thus, he is not married", we are making the implicit meaning of the term bachelor explicit without adding new information for anyone who knows how to properly use the term bachelor, which is certainly less complex than the terms *system* or *development*. This is why the tautologies that can be derived by analyzing concepts such as *the development of instrumental dynamic systems in a world with scarce resources* seemingly adds new information. However, that the information might appear to be new to most of us is due to our never having made it explicit.

The tautologies that can be derived from this concept will help to better understand the job of developing technical systems. A better understanding of one's own job allows for more efficient

work. Increase of work efficiency yields increase of productivity. Therefore, the general statements about systems that are at the heart of Altshuller's eight laws of technical system development can be called *productive tautologies*. To articulate such tautologies, the patent fund might be a resource to seek inspiration and to collect examples from all kinds of industries. However, the findings will only be valuable to the extent to which they contribute to explaining the terms in question.

Instead of trying to derive laws of technical system evolution from patent analysis, it seems to be more promising to use the patent fund as resource for validation. In 2006, [17] tested Altshuller's laws in the following manner. From [18] they took the 68 highest generality US patents from 1963-1999, which are patents that are cited by subsequent patents belonging to a wide range of *International Patent Classification* (IPC) classes. For each of these patents, the authors studied the state of the art section in order to understand the transition from the state of the art situation to the solution in the respective patent. For each of the technical system evolution trends, they checked whether or not it could have been used for developing the solution and whether or not it contradicted the transition proposed in the patent. Altogether, the 68 patents provided examples for each of Altshuller's laws, while 3 patents provided counter-examples concerning *law 2)* energy conductivity, *law 5)* uneven development of a system's parts, and *law 8)* increasing use of su-fields. Unfortunately, we could not get in touch with the authors of [17] and gain access to supplementary materials to view the counter-examples. However, as our above analysis has shown, the contradicted laws are conditional. Law 2 does not hold for static systems, law 5 is not valid when the product was developed from a holistic standpoint, and law 8 depends on efficiency concerns, which allows for the possibility that a mechanical solution is more efficient than its non-mechanical predecessor.

5 Literature

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