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# Process thinking — a new paradigm for science and engineering

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**Abstract**

As our research related to sustainability has progressed, we have realized that knowledge is not the prime problem. We believe that the ruling paradigm of science, engineering and policy needs to be critically evaluated. This paradigm holds that everything can be reduced to the tiniest particles which interact in a clockwork-like fashion. However, new discoveries have lead to the concept of 'systems thinking'. Systems thinking is particularly important in dealing with our environmental problems and other large-scale open-ended problems. But is systems thinking sufficient? We intend to show that systems thinking is a major step in the right direction, but it is insufficient in handling the increasing environmental problems of our planet. We believe that 'process thinking' is a better paradigm due to the profound importance of change and continuous improvement. The superficial understanding of change in science and engineering has, in our opinion, resulted in what we call the 'Dogmas of Science and Engineering' which are the main roots of our problems. A new paradigm must therefore *violate* these dogmas for mankind to overcome the problems we are facing. This new paradigm must permeate the whole of society as well, and hence both scientific and political leadership is crucial. 

## 1. Introduction

> Life is no thing or state of a thing, but a continuous movement of change — S. Radhdkrishnan.

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When Charles Darwin published his work on evolution and natural selection of species in 1859 — *On the Origin of Species*, many were convinced that this was the end of religious philosophy and mysticism. This was the finial triumph of the ruling paradigm, as Barlas and Carpenter [3] call it — a paradigm based on reductionism and foundationalism where everything can be explained in terms of chemical processes and the basic building blocks of nature, the atomic particles. However, in the early nineteen hundreds several events took place that forever changed our world view — quantum physics and relativity theory were two of the most important that totally ruined the Newtonian world view. In the words of Albert Einstein (see Capra [8]):

> It was as if the ground had been pulled out from under one, with no firm foundation to be seen anywhere, upon which one could have built.

More shocking news for those subscribing to the ruling paradigm came around 1930 when Kurt Gödel (see Gödel [21]) presented his incompleteness theorem which essentially proved mathematically what Wittgenstein [49] had said earlier. That is, logic (i.e., mathematics) was merely a tool that was consistent within itself and was 'content free'. Hence, objectivity and formality are illusions. This is something we learned about quite accidentally, and now it makes a lot of sense why; this great discovery was simply too shocking for the scientific community that it is not being taught to anyone. As Quine [35] states about empiricism: "we choose a particular way of doing it [accommodate a theory to an experiment] not because some absolute scientific principle but *because it is convenient, causing minimal disturbance in the existing theory*" [emphasis added].

Hundreds of years of systematic denial of work that does not fit the ruling paradigm, has now mounted up to a series of extreme problems in both the natural world (see Brown [7]) and even the financial world (see Gates [18]) that is impossible to solve with the current way of thinking, in our opinion. We believe it is time to go back to the roots of the ruling paradigm to identify the flaws and then go forward to make sure that those flaws are not a part of the new paradigm.

Ironically enough, it is in the most ancient of ancient, and terribly obvious, knowledge of mysticism where the answer seems to lie in our opinion. Everything is *process* — and not just that, the processes cause continuous change. Thus, structures are temporary constructs. In this light, we immediately realize that there are no such things as 'basic building blocks', 'fundamental equations' or 'laws'; there is only a basic process. In Taoism, which is one of the religions/philosophies that most clearly focuses on change, this process, which is the origin of all other processes, is referred to as *Tao*. Although Tao is emptiness, not-being and above all non-action, it is not without its efficacy, which is called *Tê* (virtue) (see Eichorn [15]). According to *Tao Tê Ching*, "Tao produces and Tê rears all beings". Hence, Tao continuously shapes our world at both micro and macro level. Before we proceed, it should be noted that in Hinduism as well as Buddhism they have similar ideas. In fact, Capra [9] claims that the world view of modern physics and the eastern religions of Hinduism, Buddhism and Taoism are essentially the same although expressed differently. We believe that the same holds for the mystical traditions of Judaism and Christianity — for example, Kabbalah (see, e.g., Shimon Halevi [43]). However, for political and religious reasons and because Taoist texts more explicitly refer to change, we find Tao a more suitable term. There is, in other words, a basic 'oneness' in the universe since everything is a result of Tao. The essence of the world [1] is therefore change, which can only be understood as a process.

Capra [10] presents a good overview of systems thinking and, as most systems thinkers, embraces the idea of *relationships*. Furthermore, Capra claims that systems thinking and process thinking are the same. In this paper, however, we shall show that this is not the case and that process thinking represents a generalization of systems thinking that is needed to overcome today's pressing environmental and social problems. First, we need to introduce some important 'Dogmas of Science and Engineering' before we analyze change in Section 3. The difference between systems thinking and process thinking is then shown in Section 4. Closing remarks are found in Section 5.

## 2. The Dogmas of Science and Engineering

> As far as the laws of mathematics refer to reality, they are not certain; and as far as they are certain, they do not refer to reality — Albert Einstein.

We identify three important dogmas of engineering and science: (1) Objects, (2) Categorization and (3) Knowledge. These dogmas determine what we view as truth, our place in the world, our relationships with each other and with the rest of Creation, and so on. In the three subsequent sections we present these three interrelated dogmas that we believe are major sources of most of the problems we face today.

### *2.1. The Dogma of Objects*

In antiquity, especially in Greece, 'objects versus processes' was one of the big issues. On one side was Heraclitus of Ephesus, who believed that objects are mere temporary bodies in the general flux and are not sharply separated from each other (see James [24]).[2] This process philosophy was strongly opposed by Parmenides of Elea (in southern Italy) and his two main disciples, Zeno of Elea (not the Stoic) and Melissus of Samos. These three were known as the Eleatics. "The main tenet of these philosophers was that any kind of change was impossible, and so (on the usual interpretation) was any kind of plurality. Reality was one and unchanging, and the changing multiplicity of things was an illusion. The arguments used, appealed to

[1] A more appropriate term is *existence*.

[2] Lecture 6; a clear, readable and sympathetic exposition of some of Bergson's philosphy, which had Bergson's full approval (Bothamley [6]).

strict logic, and the Eleatics were the first to do so systematically" (see Guthrie [20]). To bridge these ideas the notion of an atom was launched by Democritus and Leucippus, and further developed by Epicurus a century later. Matter consisted of tiny, indivisible, indestructible and unchanging tiny bits of solid stuff, differing in shape and size, and jostling each other in the void to constitute the material world. They were responsible for colors, smells, tastes and so on, but did not themselves have them (see Bothamley [6]). Nevertheless, the notion of basic building blocks was the one that prevailed, and influenced significantly people like Copernicus (1473–1543), Gallileo (1564–1642), Descartes (1596–1650) and not to mention Sir Isaac Newton (1642–1727). The whole Western world (in particular) has therefore been a firm believer of this more than two-thousand-year-old dogma. It was not until quantum physics and relativity theory came around that this dogma was scientifically questioned seriously. However, in society, the notion of objects is dominating the notion of processes.

A paramount problem of the Dogma of Objects is that it leads to the next dogma as a logical extension — the Dogma of Categorization. However, an equally serious result, and assumption, that lead to the Dogma of Objects is the belief that our world is *unchanging*. This myth is rooted strongly in us. For example: we build things and expect them to last; we are surprised by El Niño; in most medicine TV commercials the sole focus is on the objects that can cure you (i.e., the medicine) and not on the processes that lead to the illness in the first place; the general trend in society of solving problems by attacking the symptoms and not the causes. In other words, change has been viewed as something superficial and temporary in our society, which is in accordance with the ideas of the Eleatics. However, if we study nature and all human societies, we find reason to believe the opposite — change is the very essence and even foundation of life.

### *2.2. The Dogma of Categorization*

Although Aristotele (384–322 BC) was oriented towards the 'continuous' theory of matter, with no void (see Bothamley [6]), he played an important role for over two thousand years through his model of the world which was supported by the Church throughout the Middle Ages. He also divided humans into two *separate*[3] parts — body and soul. However, if we look to India for example, where Hinduism is strong, there is no separation between the religious and daily life; in fact, there is *no* Hindu term for religion (see Renou [37]). Clearly, the division *within* ourselves impacts the lives we live and how we think about ourselves; combined with the Dogma of Objects, this can (and unfortunately has) lead to a strong focus on 'things' — materialism, the popular, but uncommon in Philosophy, definition of which is to emphasize the value of material things (see Quinton [36]).

Aristotele also systematized and organized the scientific knowledge from Antiquity (see Capra [9]). Further development did not take place until the Renaissance prob-

[3] As opposed to *complementary* parts.

ably because of the Dogma of Objects (in the sense that they thought they knew what was to be known) and the firm grip the Church had in Europe (the Inquisition was very active). It should, however, be noted that the Church has never been hostile to scientific advance (see Corbishley [12]), and the tension between Church and Science can be attributed to, on one hand, the way scientific discoveries were presented to oppose religious truths and, on the other, some theologians being nervous about its possible repercussions in their domain. In fact, hostility has often originated from the side of science (see Corbishley [11]). Nevertheless, the work of categorization of Aristotele was to live on, up to today (and probably into the unforeseeable future). In fact, many terms used in engineering and science today can be traced back to Greece.

Categorization is, of course, a necessity in society and in our lives so that we can communicate easily. However, the Dogma of Categorization has lead to a *very strict division* of disciplines, organizations and society in general — and even within ourselves. This is the reason why higher factory chimneys were seen as a solution to pollution some decades ago. We did not understand that everything affects everything — that our categories are not real but are rather illusions of our mind. This fact has been shown in chaos theory, whose beginning was marked by the Lorenz model and from which the half-joking assertion that a butterfly stirring the air today in Beijing can cause a storm in New York next month — known as the 'butterfly effect' — was derived (see, e.g., Gleick [19] and Mosekilde and Feldberg [30]). We also see this tendency of categorization in, for example, TV, where medicine commercials focus on controlling the problem without seeking a solution to the causes of the problem, which often is in a totally different category of knowledge. This blindness for the wholeness, combined with the belief that things are in essence *not* changing, have given good breeding ground for initiatives where solutions to problems produce more problems than the one solved, which is a result of suboptimization. Striking examples of this are, for instance:

1. the introduction of 1,1,1-trichloro-2,2-bis-(*p*-chlorophenyl) ethane ($C_{14}H_9Cl_5$) — better known as DDT — in agriculture, which later proved to be a disaster for predators on the top of food chains, for example, through infertility and miscarriage;
2. the introduction of European or American animals into new ecosystems such as Australia and Hawaii, which eradicated parts of local flora and fauna.

The next dogma — the Dogma of Knowledge — amplifies these problems, as discussed next.

### *2.3. The Dogma of Knowledge*

Once the Dogmas of Objects and Categorization were well established, the next step was to investigate the world of objects, categorize the world itself and increase our knowledge about it — i.e., the role of science. Two important men in this context are Descartes and Galileo. Galileo was one of the first *true* scientists we know about, and he is consequently referred to as the father of modern science. His big contribution to science was the notion of combining empirical knowledge with mathematical logic. A much stronger formulation of the role of logic is, however, found in Descartes [14], where the famous quote "*Cogito ergo sum*" (I think, therefore I am) is found. This may be one of the strongest formulations on the importance of logic in history — not even the Greek philosophers formulated it as strongly as Descartes even though the Greeks placed logic as one of three elements (see Long and Sedley [26]) in philosophy (the two other were physics and ethics). From this historical background the scientific method of abstraction was introduced. There are two basic ways of doing research:

1. observe nature and describe the studied phenomenon using logic and mathematics;
2. derive some properties about a phenomenon using logic and mathematics, and then observe nature to see if the derived results fit the empirical results.

Both these two basic ways of conducting scientific work are commonly combined with reductionism, or reductivism, and foundationalism, as discussed by Barlas and Carpenter [3]. Reductionism is based on the belief that the whole can be reduced to smaller entities (see Agazzi [1]). The purpose is obviously to make the analysis simpler, and this approach has been widely accepted, particularly by empiricists and nominalists. The culmination of this view is the Principle of Parsimony (Ockham's Razor) which states that "in general, one should pursue the simplest hypothesis". This creates a problem concerning the role of simplicity in science (see Bothamley [6]): e.g., how simple is simple, to what degree is simplicity related to performance of models and what are the trade-offs? The first strong opposition to this mechanistic paradigm came in art, literature and philosophy (see Capra [10]), and in gestalt psychology it was recognized early that the whole is different than the sum of its parts (see Ellis [16]). Eventually, systems thinking came out from biology, psychology and ecology, and culminated in the controversial Gaia hypothesis proposed by Lovelock and Margulis. In this hypothesis, all animals, plants and human activities are believed to contribute to the system — Gaia — the goddess Mother Earth according to Greek mythology. The stability of the atmosphere over many eons is cited as evidence for this theory (see Lovelock [27]). In dealing with systems of such vast complexity, scientists find the usage of approximated values necessary. Knowledge, in systems thinking, is therefore no longer fixed, but *approximate*. Numbers have been replaced by probability distributions and qualitative assessments. However, the essence of the knowledge is still numerical even though the focus has changed from analysis to synthesis, and the knowledge is still in the realm of the material world. That is, everything must be within our common perceptual range. Although systems thinking has recognized some limitations of numbers, the belief in numbers is still very strong in society. This firm belief in numbers is a very old concept, first presented by Pythagoras, who simply stated that "All things are numbers" (see Russel [39]). This is deeply rooted in engineering and science, as this quote of Lord Kelvin clearly exemplifies:

> When you can measure what you are speaking about, and express it in numbers, you know something about it; but when you cannot measure it, when you cannot express it in numbers, your knowledge is of a meager and unsatisfactory kind.

For over two thousand years we in the West have therefore been seeking *rational* knowledge either through experiments based on the scientific method or sometimes by *intuition*. Intuition has been defined in numerous ways (see Nelson and Quick [32]), but the knowledge achieved through rational knowledge and intuition is what can be referred to as *relative* knowledge, which is characterized by its dependency on a framework to have any value. For example, all measurements we make have no absolute meaning as they depend on a standard or framework. Similarly, signals and language have no meaning unless you understand the context in which they were formed. In fact, Wittgenstein [49] argues that most of the time we go around talking nonsense. Since human societies are very complex, the context will also be understood differently from individual to individual. Consequently, even though rational knowledge is based on logic and mathematically founded, the conveyance of this knowledge to other people is colored by emotional, cultural and other factors. Thus, the only ones that can maintain the rationality of rational knowledge are peers. This has severely amplified categorization and made rational knowledge incomprehensible for non-peers. Then, given the organizational distance between researchers and decision-makers (caused by deliberate categorization), decisions are rarely rational — even though the basis for the decisions is a rationale — resulting in sub-optimization and wrongful decisions. In fact, even among a group of 100% rational peers the decision made by the group will in general be irrational due to Arrow's Impossibility Theorem (see Arrow [2]) which states that; "A group consisting only of rational individuals need not exhibit transitive preferences, and in general will not".

In mystical societies around the world, experiments and empirical studies (through e.g. yoga) have also played a very important role in achieving enlightenment, as the Buddhists call it:

> Personal experience is… the foundation of Buddhist philosophy. In this sense Buddhism is radical empiricism or experimentalism, whatever dialectic later developed to probe the meaning of enlightenment — experience (see Suzuki [45]).

The approach and purpose of the mystical experiments, however, are *very* different. The goal of mystical empiricism is to achieve enlightenment through what is called *absolute* knowledge. Absolute knowledge goes beyond our daily reality as it does not rely upon our perception and intellect to abstract and categorize, but simply tries to grasp reality *directly*. The reality, from which absolute knowledge stems, is, according to Bergson [5], "not open to reason and not relying on dogma". The problem with this type of knowledge is that it is impossible to communicate to other people, even peers, in a precise and logical fashion (to the extent that is possible at all) as Lao Tzu states in *Tao Tê Ching*: "the Tao that can be expressed is not the eternal Tao". It is therefore impossible to communicate absolute knowledge directly, and it is even harder to teach it, as expressed in the Kena (Talavakara) Upanishad, 3:

There the eye goes not,
Speech goes not, nor the mind.
We know not, we understand not
How one would teach it.

Because of this inaccessibility of absolute knowledge, it has been severely neglected in the West, and today virtually all around the world. However, in psychology it has been indicated that there *is* a level of consciousness beyond the rational consciousness (or rational knowledge) (see James [23]). If this refers to absolute knowledge or intuition is hard to say, nevertheless both are virtually impossible to teach to other people, and they are not open to rational assessments (see, e.g., Pole [34] and Rowan [38]). *One* way of expressing this knowledge, however, is by apparently *illogic* and *paradoxical* parables and proverbs, such as the allegorical parables of Jesus in the Bible or, for example, when Zen Master Daito met his student, Emperor Godaigo: "We were parted many thousand *kalpas*[4] ago, yet we have not been separated even for a moment. We are facing each other all day long, yet we have never met" (see Suzuki [44]). This apparent lack of logic and paradoxes forces the listener in two possible directions — acceptance through deeper understanding (beyond logic) or rejection through logic. Particularly in the West, this type of wisdom (or absolute knowledge) has been rejected because it cannot be reasoned and established in an intellectual way. Consequently, we pose the following statement about modern human civilization: that *despite the technological development, humans are in essence the same as they were thousands of years ago*. We have simply not developed *ourselves* significantly — or as King Solomon said, "there is nothing new under the sun" (Ecclesiastes 1:9). This can also be illustrated by the fact that all activities such as lying, stealing, killing, cheating and making war that were performed, e.g., 5000 years ago, are still performed today.

Clearly, the Dogma of Knowledge applies only on a personal level and cannot be incorporated into any method or computer code, because otherwise we would have changed. The violation of the dogma must ideally be incorporated into human decision-making processes, but it requires that the decision-makers are familiar with absolute knowledge (wisdom) — which cannot be taught directly. Therefore, in the light of the increasing secularization and disrespect for philosophical, religious and mystical (or absolute) knowledge in our societies, we find little reason to believe that this negative trend will be turned round in the near future.

Likewise, the word 'enough' is becoming an extinct word in our vocabulary. To explain this better, consider Fig. 1 where we present a very famous symbol from Chinese thought[5] — *yin* and *yang*. This, according to Chinese philosophy, represents the dualistic opposites in the world as Wang Ch'ung (80 AD) describes it (see Needham [31]):

[4] Half a day of Brahma; a year of Brahma consists of 360 days or 720 kalpas.

[5] It should be noted that in Kabbalah, the mystical teachings of Judaism and Christianity, a much more elaborate system known as the Tree of Life is presented (see, e.g., Shimon Halevi [43]).

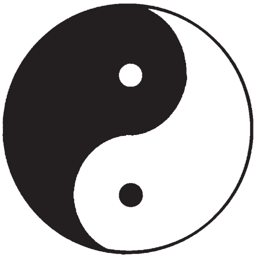

Fig. 1. Yin and yang.

> The yang having reached its climax retreats in favor of the yin; the yin having reached its climax retreats in favor of the yang.

Similar cyclic behavior has also been indicated empirically by Nikolai Kondratieff in large economic systems. He studied various economic indices for England, France and the United States between the 1780s and 1920s, and identified long (roughly 50 years[6]) economic cycles [25] that later became known as Kondratieff cycles;[7] however, these cycles remained fairly unknown to English-using economists (see Tarascio [46]). Later on, similar cyclic behavior was found in sociotechnical systems (see, e.g., De Greene [13]) and energy consumption (see, e.g., Seifritz and Hodgkin [42]), probably due to the economic long cycles. Nevertheless, the understanding of the cyclic behavior of processes and the need for *balance* is the basis for the Golden Middle Way which, in our opinion, is also neglected knowledge particularly in the West.

Our society is therefore facing a *very* serious dilemma: we are increasing our rational knowledge rapidly, but we are not gaining the wisdom to use it to the best for all mankind. Mankind is at war with itself! In our opinion, this dilemma is the single biggest problem the three dogmas have brought about, and the consequence is that *our society is in extreme imbalance*. For example:

1. environmental problems (greenhouse effect, acid rain, smog, deforestation, etc.);
2. economic problems (distribution of resources in general);
3. individual problems (loneliness, moral degradation, etc.);
4. security problems (terrorism, war between countries and nationalities, etc.);
5. political problems (corruption, lack of participation in democracies, shortsightedness, etc.).

Or, as Capra [9] expresses it:

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[6] It is interesting to note that this is also how often a jubilee occurs (Leviticus 25:10) in the Bible.
[7] This name appears to have been used first by Schumpeter [41].

> The belief that all these fragments — in ourselves, in our environment and in our society — are really separate can be seen as the essential reason for the present series of social, ecological and cultural crises. It has alienated us from nature and from our fellow human beings. It has brought grossly unjust distribution of natural resources creating economical and political disorder; an ever rising wave of violence, both spontaneous and institutionalized, and an ugly, polluted environment in which life has often become physically and mentally unhealthy.

So was everything so much better before? According to both Hinduism and Buddhism, it was (see Conze [11]), and similar thoughts are found in other religions. Horace in the West expressed it like this (Odes 3.6):

> Our father's age ignobler than our grandsires
> Bore us yet more depraved; and in turn
> Shall leave a race more vicious than ourselves.

Others disagree. We think that to some extent it *was* better before. For example, people had more time for each other and they needed each other in their daily life; the "chasing after the wind", see e.g. Ecclesiastes 2, is greater today. However, many of today's problems were just as real in those days, but there is one very big difference. Due to increased population density, communication, technology and wealth in general, an action today has bigger consequences than it did hundreds of years ago. Technological development is therefore a double-edged sword, which needs to be managed carefully — with wisdom. For simplicity, in the rest of the paper we shall use examples from the environmental problems and industry.

## 3. Mankind and change

> To be successful
> do not be rigid and immobile
> in your thinking
> but always keep abreast of the time
> and
> change with it
> Fu Hsi, *I Ching* (The Book of Changes).

In this section we investigate aspects of change and how the understanding of change *should* impact science and policy-making from a philosophical point of view. The first aspect of change we discuss is how change affects an organization (see Section 3.1). We then investigate in Section 3.2 the role of optimization, while how to implement change is explored in Section 3.3.

### *3.1. Change and the organization*

In Section 1 we showed that change is basic and inherent in our world, which implies that change is inevitable as illustrated in Fig. 2. However, change is a double-edged sword, giving possibilities for both growth and decline, depending on how well the Way of Change is understood and managed. Note that Tao can only be managed, not resisted: like a river flowing down a mountain, you can alter the course of it but you cannot stop it. In Taoism, non-action[8] is therefore highly evaluated, because only then will you be successful (see the opening quote of this section). Owing to the chance for decline it is important to be *proactive* instead of *reactive*, because then you can guide change in a preferred direction and avoid the last third of the Way of Change, which is characterized by declining results and arising new problems (see Fig. 2). The long and short lines in Fig. 2 are trigrams, which represent the opposites in the world according to Fu Hsi, a Chinese sage. The long lines represent yang — the active, masculine, etc. aspects of the world, while the short lines represent yin — the passive, feminine, etc. aspects of the world. In the *I Ching* (The Book of Changes), two and two trigrams were combined to give hexagrams (*kua*). This gives 64 possible combinations. It is interesting to note that this order is identical to the orders found in Leibnitz's binary system and in DNA molecules (see Wei [48]).

The concept of yin and yang is very similar to ideas of thesis, antithesis and synthesis proposed by Hegel. According to Hegel, "both reality itself and our thought about it (which were ultimately the same thing) developed by certain processes

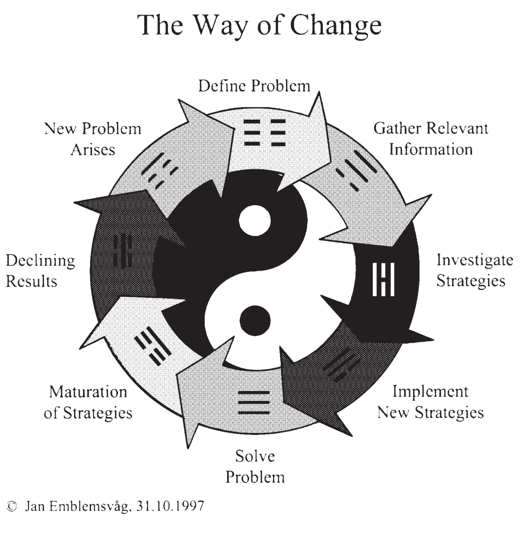


Fig. 2. The process of change.

[8] In the sense of "not going against the grain" (see Needham [31]).

occurring (the thesis) which contained within themselves the seeds of their own frustration and destruction (the antithesis). This antithesis, however, contained its own antithesis (the negation of the negation) which emerged in the form of a synthesis of the original thesis and antithesis. This synthesis then formed the thesis for the next stage in the overall process" (see Honzik [22]). Ironically enough, Marx and Engels were firm believers of the Hegelian dialectic, but they failed to see that communism would not be *the final* synthesis (see Zaehner [51]), which does not exist in our opinion.

Change management must therefore in the long run be balanced and it occurs as a result of dynamic imbalance. Thus, the only way to achieve balance is by agilely controlled imbalance in which feedback loops are crucial. This is the idea behind modern fighter planes. They are designed to be out of balance to be responsive, and this makes it impossible to fly them without the help of computers which facilitate the necessary feedback loops and controls. This is also the mechanism in Nature — the apparent stability of Nature is a result of continuous imbalance and non-action. This can be achieved in several ways, notably through symbiosis — see, for example, Margulis and Sagan [28], where symbiosis is presented as one of the major evolutionary forces. Even when catastrophic events occur, in Nature the complementary effects — creation — are just as powerful, and the initial imbalance of the system is the rescue due to the high responsiveness of such a system. It is interesting to note that without the destruction of the dinosaurs, the creation of humanity would have probably never occurred. Hence, the most potent creative force is destruction. Also, creation and destruction are complementary, and neither could exist without the other. Their synthesis is change. Non-action, as mentioned earlier, is therefore to be in internal imbalance *in phase* with the external imbalance. Non-action is therefore essentially adaptability to change.

Change is inevitable, and organizations that try to resist it will fail. It is consequently crucial for organizations to keep the Way of Change from appearing cyclic as in Fig. 2, but rather promote a continual change and momentum forward by *never* letting the strategies go beyond maturation point by non-action. Consequently, continuous improvement is the only process an organization can rely upon in the long run, because it is in accordance with the Way of Change. It is, however, important to note that continuous improvement through incremental changes is not sufficient in the *long* run; we also need *innovation*, as noted in Womack and Jones [50]. This fact has been shown in biology where a significantly different species suddenly appears. How we view the difference between change through continuous improvement and change through innovation in an industrial setting is illustrated in Table 1. The results of the process of change can therefore be illustrated as in Fig. 3. It is also important to realize that each improvement step must be *balanced* — never too much of anything in the long run, striving for the Golden Middle Way — otherwise the Tao may go its own way and be impossible to manage, often ending up as an antithesis, e.g., the French Revolution. However, as noted in Table 1, change via innovation may be resource-intensive. Thus an organization must improve continuously to survive in the short run, in order to have the resources to survive in the long run.

Table 1
Two contrasting improvement processes [40]

| | *Kaizen*[a] vs. | Innovation |
|---|---|---|
| Focus | Design, production and marketing | Science and technology |
| Targeting | Broad: | Narrow: |
| | Quality, cost, | Feature |
| | Safety, efficiency | Technique |
| | Product development | |
| Expertise | Conventional know-how | Leading edge, breakthrough |
| Capital needs | Very modest | Major investments |
| Progress | Small steps | Big jumps |
| Results | Continuous | Spontaneous |
| Visibility | Not dramatic | Very dramatic |
| Involvement | Everyone | Selected few |
| Cooperation | Group activity | Individual effort |
| Recognition | Effort, process | Results |
| | ↓ | ↓ |
| | Evolution | Revolution |

[a] The Japanese word for continuous improvement.

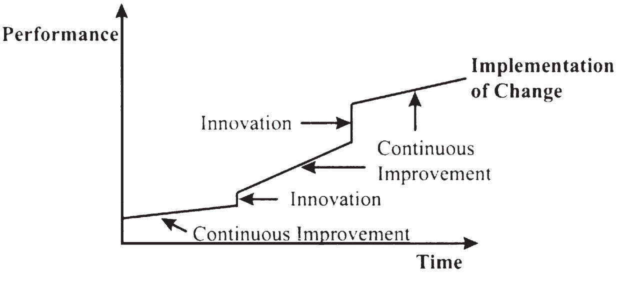


Fig. 3. Change via innovation and continuous improvement.

The dilemma we are facing is therefore how to promote and manage change by compromising short-term survival goals with long-term survival goals. In Nature this is simply solved by the process of evolution, where species come and go. Organizations must also evolve, and to resolve this dilemma we have to step back and look at one purpose of an organization: to provide return on the shareholders' investments. We have already shown that short-term survival depends on continuous improvement[9] and not innovation, because innovation is too uncertain. The shareholders therefore play a crucial role in allocating resources to innovation, instead on taking it out for short-term gains, and these resources have to be created from continuous

[9] It should be noted that other issues *not* related to change also play an important role; however, these issues are not of interest in this discussion and therefore are not included.

improvement efforts. In a wider context, 'stakeholders' is the focus, not just the shareholders. That is, if we are discussing sustainability and environmental problems, companies must allocate their resources to the best for mankind *and* Nature, which are their stakeholders. Hence, compromises are unavoidable.

The notion of optimization plays an important role in science and engineering as it has traditionally been used to find solutions by compromise, but are change and optimization combinable?

### *3.2. Change and optimization*

We have already introduced the term sub-optimization as something to avoid. However, we believe that, when it comes to the large-scale issues we are discussing in this paper, sub-optimization is inevitable simply because of the magnitude of the problems. The only question is, how can we reduce the negative effects from this sub-optimization? It is clear that a computer code can never do this job by itself — humans are needed for surveillance and to make decisions in all the steps in the process. This can best be performed by multi-disciplinary teams, as they possess large pools of *different* knowledge. Furthermore, due to the Way of Change, the (open) systems themselves exist in a state of imbalance (non-equilibrium) resulting in a non-stationary 'optimum'. Thus, optimization would be an invalid approach since the 'optimum' is constantly moving. Another issue is that even if an optimum solution could be found, the implementation of it would be impossible as this would be the opposite of non-action. Hence, the only valid, and possible, approach is to continuously improve the system in a non-action fashion.

It is interesting to note that although Capra [10] prescribes to systems thinking, he thinks that "managing a social system — a company, a city, or an economy — means finding the *optimal* [emphasis added] values for the system's variables". According to our analysis this is not feasible, and not even desirable, since an optimum solution today is no longer an optimal solution tomorrow — if an optimal solution exists at all. Consequently, we see that systems thinkers have failed to realize the implications of systems thinking. We believe that this is due to the lack of explicit focus on processes, which we discuss in Section 4.1.

### *3.3. Implementing change*

We believe that implementing change is the job for so-called *change agents*. In Nelson and Quick [32], a change agent is defined as an individual or group that undertakes the task of introducing and managing a change in an organization. If we look at society as the organization under investigation, change has often been induced by scientists and engineers via technological development. Hence, scientists and policy-makers are change agents. Science and politics must consequently support change through continuous improvement and violate the dogmas to avoid *unnecessary* (see Section 3.2) sub-optimization.

The essence of the Dogma of Objects is that things are unchanging and therefore can be described fully as objects, which can be organized into structures. To violate this dogma we simply need to state the opposite, which is that change is the essence of life and that change can only be fully described in terms of processes. Thus, science and engineering must be *process-oriented*. The process orientation also means that strategies, the usage of methods, implementation of results and the feedback loops must be processes.

As a natural and logical extension of the Dogma of Objects, we get the Dogma of Categorization. To break down these divisions caused by categorization, we need to ensure that as much *different* knowledge as possible is being drawn upon and that the entire system is considered. This can best be done by using a *cross-functional* and *multiple-objective* approach that will be employed by *multi-disciplinary teams*. Furthermore, the entire *life-cycle* must be considered.

The two first dogmas are fairly easy to violate; however, the Dogma of Knowledge is different because it primarily addresses the personal level. The Dogma of Knowledge is concerning what *is* knowledge and how can it be obtained and used. It is shown that logic and the rational knowledge have severe limitations. Consequently, science and engineering cannot be based on these types of knowledge alone — we need *wisdom* in addition. However, there is a problem with absolute knowledge (wisdom) — it cannot be taught, and thus we have to leave this to each and everyone to remember and acknowledge.

The general requirements for implementing change from a philosophical point of view can therefore be summarized as follows:

1. science and politics must be *process-oriented*;
2. science and politics be *cross-functional* and *multi-objective* in nature, and applied by *multi-disciplinary* teams;
3. the *entire life-cycle* and *value chain* must also be considered to avoid sub-optimization;
4. science and politics must apply results with *wisdom* and decisions must be made accordingly.

The problem with science and politics, as discussed in Section 2, is that none of the four afore-mentioned points are being taken seriously. However, the problems of our world view have been recognized for over a hundred years and, as a response, systems thinking emerged. In many ways systems thinking is similar to process thinking, but there are differences as well which we investigate next.

## 4. Systems thinking versus process thinking

> The problems we have today cannot be solved by thinking the way we thought when we created them — Albert Einstein.

The main characteristics of systems thinking according to Capra [10] are:

1. the focus is shifted from the parts to the whole. The main reason is that systemic properties are destroyed when a system is dissected into isolated elements; and
2. systems are nested within other systems. This is important to realize because some properties of a system are only visible, or detectable, on certain system levels.

In the next sections we discuss how these two key characteristics of systems thinking relate to the Dogmas of Science and Engineering, and we compare systems thinking with process thinking.

### *4.1. Violation of the Dogma of Objects*

Systems thinking does not recognize processes as being the essence of life, but rather relationships. As the very name implies, systems thinking focuses on *systems*, where a system is defined by relationships between objects and/or structures comprised of objects. Processes are thought of something that the system contains and are linked to each other by relationships. That means that systems thinking focuses primarily on the *result* of the processes. Consequently, systems thinking is only partially violating the Dogmas of Objects — in the sense that, by focusing on relationships, objects and structures, systems thinking implicitly assumes that everything is captured. However, this is not the case, because systems thinking does not recognize the importance of change over *time*. According to the discussion in this paper, Tao — which is a process — is the fundamental aspect of life. Everything is temporary given a long enough time span. Only change remains — the eternal interplay of yin and yang. Also, the complementary aspect of change is no change. This is, however, not physically possible in the material world; the closest approximation is a diamond. Relationships are a special form of process which represent how output and input between processes manifest themselves to form larger processes. Structures appear when objects are linked physically to produce larger objects. Thus, relationships are complementary to processes, and structures are complementary to objects, and everything stems from Tao. The web of processes and relationships constitutes organization, while the web of objects and how they are physically connected comprises the structure of a larger object. This is in accordance with Maturana and Varela [29], but they are only concerned with *living* systems.

When systems thinking is applied within the context of non-living systems, however, it stops at relationships at best. For example, in the design of products, systems thinking would focus on the functional output of the system as a whole, the function of the various components and the like. Process thinking, however, would focus on what the system does in every aspect. This difference may seem academic, but it is truly significant. A systems approach would focus on how to better relate the components to benefit the whole; in contrast, a process approach focuses on what the system actually does. Then, components can relate, be combined or separated depending on what is beneficial for the whole. From this we realize that systems thinking *can* be the same as process thinking in respect to the Dogma of Objects, but because of the lack of explicit process focus, the process view is easily lost. This is the case in the new ISO 14000 Environmental Management Standard, in our opinion. Bergman [4], Tibor and Feldman [47] and others claim that the ISO 14000 standard is the environmental management system equivalent of the ISO 9000 quality management system, which Bergman [4] claims is process-oriented. But that is only on the strategic level of the standard where all the right buzzwords are used; once you go into the details of the standard, it becomes clear that it uses the same old reductionist way of thinking (see Emblemsvåg and Bras [17]). This clearly illustrates a very important point: that unless something is explicitly defined and handled, it will soon become a forgotten part of the whole. As the old accounting dictum states: "what gets measured, gets managed". This follows as an antithesis to the learning of systems thinking, the synthesis is that systems thinking no longer is holistic. For process thinking it is different. The antithesis of learning process thinking is forget about objects and structures, but because of our inherent need and tendency to think in terms of objects and structures, little is lost. The synthesis is therefore *true* systems thinking.

Systems thinking therefore seems to have the potential of violating the Dogma of Objects, but in reality it rarely occurs, particularly in the case of non-living systems. The explicit focus on change and process in process thinking results always in a violation of this dogma. Process thinking is therefore slightly different in our opinion; this difference is very important in our research, and possibly in policy-making and science in general.

### *4.2. Violation of the Dogma of Categorization*

Systems thinking primarily came around due to the Dogma of Categorization. More and more scientists realized that reductionism was incapable of producing satisfying results in their research. Recently, this is the case of so-called psychosomatic networks (see Pert et al. [33]). Traditionally, the nervous system, the endocrine system and the immune system were studied in three separate disciplines — neuroscience, endocrinology and immunology, respectively. But now it seems that these three systems really are only one system.

Process thinking forces one to follow the course of the process — the relationships, which means that categories have no meaning in process thinking unless they represent a boundary for the process. Similarly, systems thinking forces one to investigate all the relationships within the system, and categories only have meaning if they represent the actual system boundary of the relationships. Hence, there is little, if any, difference between systems thinking and process thinking with respect to the Dogma of Categorization.

### *4.3. Violation of the Dogma of Knowledge*

The only way to violate this dogma is by wisdom, or absolute knowledge. Neither systems thinking nor process thinking deals with wisdom, because it cannot be taught. Consequently, violation of this dogma will only occur if humanity moves away from the blind faith in rational knowledge towards a synthesis with the ancient wisdom of life. The synthesis of wisdom and rational knowledge is, in our opinion, the Way of Change.

## 5. Closing remarks

> By wisdom a house is built and through understanding it is established,
> through knowledge its rooms are filled with rare and beautiful treasures.
> King Solomon (Proverbs 24:3).

We have provided a short philosophical review of engineering and science through the formulation of the three Dogmas of Science and Engineering — the Dogmas of Objects, Categorization and Knowledge — and tried to relate this to policy-making as well. In our opinion, these dogmas are the prime reason for most of today's problems. A second important related issue that we have addressed is the philosophical aspects of change, and how change must be introduced and managed by change agents in an organization through continuous improvement and long-term commitment to innovation. For science and politics this implies that:

1. science and politics must be *process-oriented* and *change-oriented*;
2. science and politics must promote *cross-functional* and *multi-objective* works that will be done in *multi-disciplinary teams*;
3. science and politics must consider the *entire life-cycle* of whatever is done or made;
4. science and politics must apply their result with *wisdom*.

We have shown that process thinking is the only paradigm that supports all of the three first requirements. The fourth requirement is beyond any paradigm since wisdom cannot be taught in conventional ways. Systems thinking is in many respects similar, but there is one big difference — the process orientation is suffering, leaving relationships as the primary area of concern. On one hand, since relationships and processes are complementary, systems thinking *does* implicitly focus on processes; but on the other hand, most practitioners of systems thinking seems to miss the process view. Process thinking is therefore a better paradigm because it incorporates systems thinking and in addition focuses more explicitly on *all* aspects of reality — processes, relationships, objects and structures — process being the basis; the oneness.

In practical life, this seemingly academic difference has large consequences. For example, the new ISO 14000 Environment Management Standard is clearly influenced by systems thinking, but the process orientation is mostly lost. This has dramatic impact upon the effectiveness and efficiency of the standard, as illustrated by Emblemsvåg and Bras [17].

Hence, process thinking is not the same as systems thinking; it is the philosophy and thinking of systems change through non-action, where processes and relationships are complementary aspects of an ever-changing reality governed by Tao. Thus, from the religious/philosophical thesis of Antiquity and the antithesis of Newtonian mechanism the synthesis of process thinking can arise, and from the thesis of wisdom and the antithesis of process thinking a better world can be synthesized. A better world cannot, however, arise from a paradigm shift without our conscious vision, commitment and desire for a better world. Thus, in the words of King Solomon: “Where there is no vision, the people perish”.

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## References

[1] Agazzi E. The problem of reductionism in science. In: Colloquium of the Swiss Society of Logic and Philosophy of Science. Zürich, Switzerland: Klüwer Academic Publishers, 1991.
[2] Arrow KJ. Social choices and individual values. 2nd ed. New Haven, CT: Yale University Press, 1963.
[3] Barlas Y, Carpenter S. Philosophical roots of model validation: two paradigms. System Dynamics Rev 1990;6(2):148–66 Summer.
[4] Bergman AJ. What the marketing professional needs to know about ISO 9000 series registration. Ind Marketing Manag 1994;23:367–70.
[5] Bergson HL. The two sources of morality and religion. Garden City (NY): Doubleday, 1935.
[6] Bothamley J, editor. Dictionary of theories. London: Gale Research International, Inc, 1993.
[7] Brown LR. State of the world. Washington (DC): Worldwatch Institute, 1992.
[8] Capra F. Uncommon wisdom. New York: Simon & Schuster, 1988.
[9] Capra F. The Tao of physics. 3rd ed. Boston (MA): Shambhala, 1991.
[10] Capra F. The web of life. First Anchor Books ed. New York: Anchor Books/Doubleday, 1996.
[11] Conze E. Buddhism: the Mahayana. In: Zaehner RC, editor. Encyclopedia of the world’s religions. New York: Barnes & Noble Books, 1997.
[12] Corbishley T. Christianity: the Catholic Church since the Reformation. In: Zaehner RC, editor. Encyclopedia of the world’s religions. New York: Barnes & Noble Books, 1997.
[13] De Greene KB. Long wave cycles of sociotechnical change and innovation: a macropsychological perspective. J Occupat Psychol 1988;61(March):7–23.
[14] Descartes R. Meditations on the first philosophy. 1979 ed. Indianapolis (IN): Hackett Publishing Company, 1979.
[15] Eichhorn W. Taoism. In: Zaehner RC, editor. Encyclopedia of the world’s religions. New York: Barnes & Noble Books, 1997.
[16] Ellis AD, editor. A sourcebook of gestalt psychology. London, 1938.
[17] Emblemsvåg J, Bras B. ISO 14000 and activity-based life-cycle assessment in environmentally conscious design and manufacturing: a comparison. In: 1998 ASME Design Engineering Technical Conference. Atlanta (GA): American Society of Mechanical Engineers, 1998.
[18] Gates JR. The ownership solution. Reading (MA): Addison-Wesley, 1998.
[19] Gleick J. Chaos. New York: Penguin, 1987.
[20] Guthrie WKC. A history of Greek philosophy, vol. 2. Cambridge: Cambridge University Press, 1962.
[21] Gödel K. In: Feferman S, editor. Collected works, volume I, publications 1929–1936. New York: Oxford University Press, 1986.
[22] Honzik MP. Life-span development. Annu Rev Psychol 1984;XXXV:309–31.
[23] James W. The varieties of religious experience. New York: Longmans, Green & Co, 1935.
[24] James W. A pluralistic universe. In: The works of William James, vol. 29. Cambridge (MA): Harvard University Press, 1977.
[25] Kondratieff ND. Bol’shie tsikly kon’yunktury (Long economic cycles). Voprosy konyunktury 1925;I(1).

[26] Long AA, Sedley DN. The Hellenistic philosophers, vol. 1. Cambridge, 1987.
[27] Lovelock JE. The ages of Gaia: a biography of our living earth. New York: Norton, 1988.
[28] Margulis L, Sagan D. Microcosmos. New York: Summit, 1986.
[29] Maturana H, Varela F. Autopoiesis: the organization of the living, 1980.
[30] Mosekilde E, Feldberg R. Nonlinear dynamics and chaos. Lyngby, Denmark: Polyteknisk Forlag, 1994.
[31] Needham J. Science and civilization in China. Cambridge: Cambridge University Press, 1956.
[32] Nelson DL, Quick JC. Organizational behavior. 2nd ed. St. Paul (MN): West Publishing Company, 1997.
[33] Pert C, Ruff M, Weber R. Neuropeptides and their receptors: a psychosomatic network. J Immunol 1985;135(2):820–6.
[34] Pole D. Conditions of rational inquiry. London: Athlone Press, 1961.
[35] Quine WV. Two dogmas of empiricism. In: From a logical point of view. Cambridge (MA): Harvard University Press, 1953.
[36] Quinton A. The nature of things, vol. 9. London/Boston (MA): Routledge and Kegan Paul, 1973
[37] Renou L. Hinduism. In: Gard RA, editor. Great religions of modern man. New York: Washington Square Press, 1963.
[38] Rowan R. The intuitive manager. New York: Little, Brown, 1986.
[39] Russel B. History of western philosophy. New York: Simon & Schuster, 1945.
[40] Schneiderman AM. Metrics for the order fulfillment process (Part 1). J Cost Manag Manuf Ind 1996;(Summer):30–42.
[41] Schumpeter JA. Business cycles. New York: McGraw-Hill, 1939.
[42] Seifritz W, Hodgkin J. Nonlinear dynamics of the per capita energy consumption. Energy 1991;16(3):615–20.
[43] Shimon Halevi Z. Kabbalah — tradition of hidden knowledge. In: Purce J, editor. Art and imagination. London: Thames and Hudson, 1992.
[44] Suzuki DT. The essence of Buddhism. Kyoto: Hozokan, 1968.
[45] Suzuki DT. On Indian Mahayana Buddhism. New York: Harper & Row, 1968.
[46] Tarascio VJ. Kondratieff's theory of long cycles. Atlantic Econ J 1988;XVI(December):1–10.
[47] Tibor T, Feldman I. ISO 14000: a guide to the new environmental standards. Chicago (IL): Irwin Professional Publishing, 1996.
[48] Wei W. I Ching life. Los Angeles (CA): Power Press, 1996.
[49] Wittgenstein L. Tractatus logico-philosophicus, 1921.
[50] Womack JP, Jones DT. From lean production to the lean enterprise. Harvard Business Rev 1994;72(1):93–103.
[51] Zaehner RC. Dialectic materialism. In: Zaehner RC, editor. Encyclopedia of the world's religions. New York: Barnes & Noble Books, 1997.