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and Spirit: Time and Consciousness

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SUBSTITUTIONAL RELATIONSHIPS BETWEEN ENERGY, TIME AND INFORMATION

by

Daniel Spreng
Head, Research Group (Energy Analysis)
Swiss Federal Institute of Technology
Zurich, SWITZERLAND

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Abstract

To conserve energy one requires time and information. Similar substitutional relationships between time, energy and information can be observed frequently in technical systems: The purpose of most machines, for instance, can be viewed as beeing the saving of, or the liberation from time, at the cost of energy and know-how (i.e. information). The three substitutional pairs are examined in turn and the effect of controlling time by technological means at various levels of human experiance is examined. In addition, the measurability of time, energy and information is examined in conjunction with the ability to represent value and a classification of the sciences is suggested, according to this ability and according to how accurately they measure the three entities.

Contents

Introduction

During 1975/76 the author had the opportunity to take a leave from his job in industry to spend nine months at the "Institute for Energy Analysis" in Oak Ridge, Tennessee. The work in this think tank, headed by Alvin Weinberg, revolved around the design of strategies for the US to cope with the energy crisis. At that time hardly any one questioned whether an energy crisis existed or not. Energy was one of the top priority issues of national and international politics.

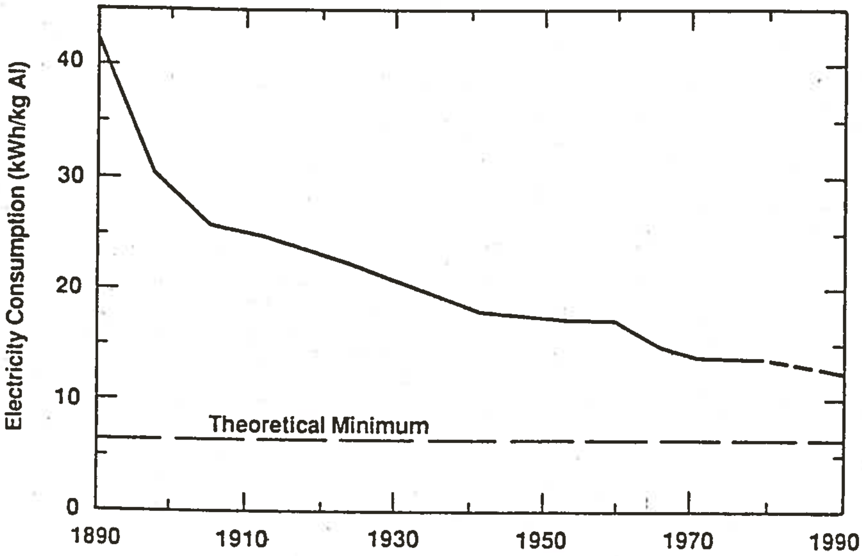
A key question in the design of these energy strategies was the possible role of energy conservation. The conventional approach, in answering that question, is to examine a number of energy conserving technologies, estimate their conservation effect in one or a few cases and then, make some assumptions on the speed of their diffusion throughout the economy.

Coming from an energy intensive industry, the author had experienced that incessant conservation efforts over the years made processes more and more energy efficient. The first industrial pieces of equipment to produce matallic aluminum from aluminum oxide were put in place concurrently in the US and in Europe soon after the 1880'ies, when Hall in the US and Héroult in Europe indepenently found a technique to perform the required chemical reaction, with the help of electrical energy, in a way that was suitable to be scaled–up to an industrial process. This so–called electrolytic process remained unchanged in principle over a hundred years now, but it's efficiency was improved by a factor of three, i.e. the specific energy consumption (direct current requirement of electrolytic cell) was reduced from over 40 kWh per kilogram of metal in 1890 to 13 kWh per kilogram of metal in new plants today.

One of the main obstacles in making aluminum smelters more efficient is that one does not have infinite time for performing the process. The velocity of the process causes resistive losses, turbulence and re–oxidation of the product. The ultimate limit to conservation obviously had something to do with the thermodynamic limit (see Figure 1). The process illustrates one of the first lessons in thermodynamics: The thermodynamic maximum efficiency can only be approached by performing processes infinitely slowly.

The question arose, whether this basic rule of physics was not also a useful guide in considering energy strategies for more complex systems, perhaps even for nations. Indeed, in transportation for instance, reducing the speed limit does save energy. The general idea

Figure 1: Energy requirement (DC current only) of new electrolytic cells to produce aluminum from aluminum oxide [1].



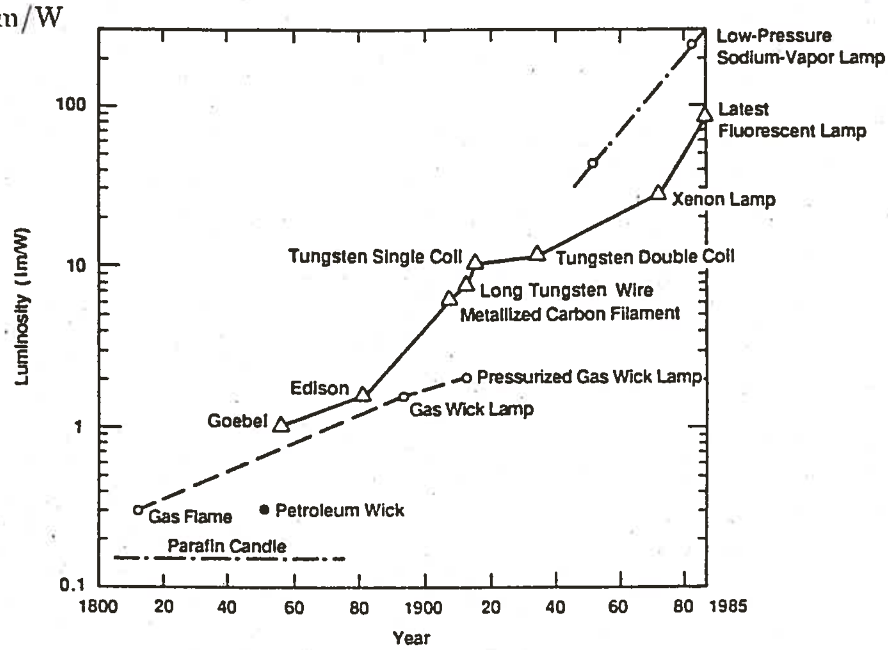
is, of course, not new at all, it has been experienced over the years by everyone and cast in the popular saying: "Haste makes waste".

Obviously, time is not the only constraint to energy conservation. It is the classic task of applied research and engineering to make processes and equipment more productive *and* efficient, i.e. to make them more efficient without going the easy route of slowing them down. In the case of the development of lighting, it is a succession of totally new inventions and in turn the improvement of each of them, that paved the path towards more and more efficient lamps. In Figure 2 an improvement of lighting efficiency of a factor of one thousand over the last 200 years can be seen. Today's energy saving lamps (in Figure 2: latest fluorescent lamp) produces 100 times more light for the same energy input as the first electric light by Goebel in 1860 or almost 1000 times more light than a candel.

Besides know–how and scientific discoveries, other forms of information, such as knowledge of the future can help energy conservation. In politically and economically stable periods one is reasonably sure of what to expect from the future and one can make investments accordingly: buy solid and efficient equipment, build good, energy–conserving houses etc.

These observations lead to regard the *lack of information* to be another factor — besides the lack of time — that may limit the potential for energy conservation. A triangle (Figure 3) was used to illustrate the point [2]. In order to make sure, that nobody took the idea

Figure 2: The luminosity, i.e. the light produced per given energy input, has increased 1000–fold over the last 200 years [1].
The thermodynamic limit is not too far away: depending on the exact wave length of the light, at about 680 lm/W

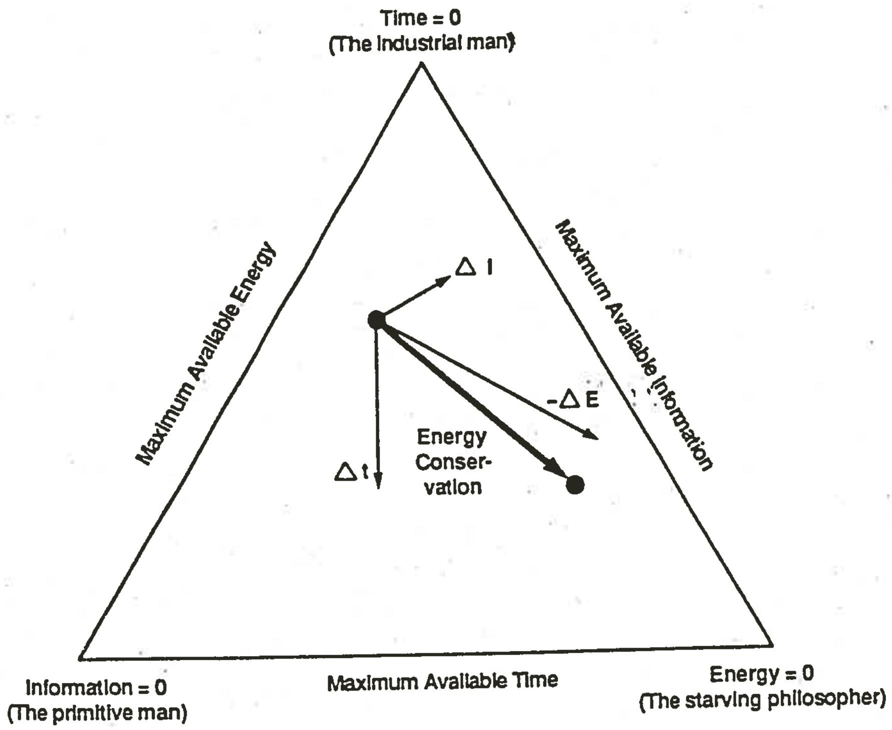


to be something quantitatively precise, the extreme positions in the corners of the triangle were given names outside of hard science: the primitive man; the starving philosopher; and the industrial man.

Each point inside the triangle represents a possible mix of energy, information and time necessary to accomplish a certain task. If much energy is required, the point will be at the upper left side of the triangle; if less energy is used, the point moves towards the opposite corner marked with energy equals zero, E = 0. Two methods of accomplishing a job with the same amount of energy are represented by points lying on a line parallel to the side of maximum energy use. Near the corners of the triangle are the situations of the starving philosopher (near E = 0), who employs much information and time to perform a task; of primitive man, perhaps in a slash and burn society (near zero information, I = 0), who because of little information, requires much time and energy (a large area of forest) to meet his needs; and of industrial man (near zero time, t =0), who with much information and energy accomplishes things very quickly.

At first, the triangle (Figure 3) was thought of as an illustration of the possible limits to energy conservation. In the following section the question is asked, whether the triangle has a more general significance. The triangle suggests a mutual substitutionability of the three quantities time, energy and information. The issue at task is how fundamental this

Figure 3: The time–energy–information triangle [2].



substitutionability might be. The three substitutional pairs are discussed separately, with particullar emphasis on the role of time[1].

1 Most Machines are Time Machines

1.1 Energy for High Speeds

A car will not require necessarily more energy, the faster it travels. Depending on the relative importance of the various mechanisms of energy dissipation (rolling resistance of the tires, air resistance and friction inside the engine, which in turn depends on the selected gear), gasoline is best saved by travelling at a constant speed of about 40 miles per hour. However, at speeds above this optimum, the faster it travels the more gasoline is reqired to travel a given distance, i.e. the substitutionability of time and energy is given.

For the hurried driver, speed of travel is limited by trafic regulation and to save time, he has to buy a powerful car, that can accelerate in a short time. As it turns out, more powerful cars will also tend to have a higher energy consumption; not only during acceleration, but also when travelling at steady speeds.

If we look closely what happend in the development of the aluminum electrolysis, mentioned above, the energy efficiency is improved over the century through a continual effort in process engineering, that aimed at slowing down the energy dissipating process step, without reducing the productivity of the over-all process. The energy is dissipated by the aluminum ions and oxygen ions travelling through the electrolyte, in which they are dissolved. The liquid electrolyte floats between the carbon anode, immersed in it from above, and the liquid aluminum, acting as cathode below. All the engineering effort over the years had to do with making that layer thinner and wider, so that the ions could travel at a smaller energy cost to the respective boundaries: the aluminum ions to the aluminum bath below and and the oxygen ions to the carbon cathode above (beeing converted there partly to carbon dioxide, partly to oxygen gas). Thanks to the ever thinner layer and the ever larger surface of that layer — the cells grew over the century from dimensions of a meter in diameter to several meters in width and a few hundred meters in length — the productivity could even be increased considerably, inspite of the slower travelling speed of the ions across the electrolyte layer.

Also in the important area of heat exchange, increasing the surface leads to higher energy efficiency. With larger heat exchanging surfaces, the same amount of heat can be exchanged at a smaller temperature difference. This makes the process occur nearer the thermodynamic ideal of extremely slow exchange with no loss at all. Similarly, in the case of insulation, slowing down heat flow with better insulation will lead to less energy dissipation and waste.

All these observations an the level of machines and processes seem to add up on the level of a nation. There seems to exist some correlation between the average number of working hours of citizens of a country and the respective per capita energy use. At least in industrial countries, the more leisure time is available, the shorter the working hours are, the more energy is used [2]. Although this data is not proof of any causal relation, one can consider it as support of a possible substitutional relationship between working hours and energy use on a national level.

Considering this observation in conjunction with the often quoted correlation of national energy use and gross national product, we can conclude, that energy is generally not only used to produce more goods and services, but to do that also in a shorter time.

1.2 Information Technology

Like energy and time, energy and information are connected at various levels by obvious as well as by subtle relationships.

A number of years ago, the late Patrick E. Haggerty, then honorary chairman of Texas Instruments, gave a lunchon speech in honour of Bardeen, Bratain and Shockley, the inventors of the transistor [4]. In his eloquent speech, he encouraged the electronics industry to contribute to the solution of the energy problem: If one tenth of the fast growing production of electronic components would be used for energy conservation, the US economy could expand rapidly without any increase in energy use.

A recent study [5] set–out to examine Haggerty's claim that new information technology, NIT, could substitute for any additional energy use of a growing economy.

At the level of single tasks the substitutional relationship could, in general, be confirmed. Although new information technology, such as computers, telecommunication and microelectronic control devices, require electricity — the electricity consumption of computers alone amounts to 2.5% of the Swiss total consumption — and the electricity use caused by a "second wave of mechanization" (robots etc.) is very important in the longer run, the applications of NIT lead to savings that, in most cases, are larger.

Microelectronic control is not only widely used to control the energy used in processes, but, more importantly also controls processes to make them faster, more accurate and better coordinated. The influence of this is a revolution in manufacturing. The impact on energy demand is a large saving per output. The savings are mostly not a result of measures specifically intended to control energy use, but significant, indirect savings result from the control of processes in general.

Even in the service sector, energy requirement per output is often lowered by NIT. If the task a computer center of a bank performs would be done "manually", it would require such a large number of bookkeepers, secretaries etc., that lighting their workspace, alone, would require as much electricity as the computer center.

In attempting to estimate the influence of such changes at the level of economic sectors, the tentative results for the various sectors are different. In the industrial sector it is conceivable, that a rapid growth will not require more energy than slower growth, since in a high–growth scenario, the energy efficient, NIT–associated investments are likely to increase very much faster than in a lower–growth scenario. In the service sector, the dominant influence of NIT–diffusion is likely to be the proliferation of services offered. In addition to new services created by applying NIT, other services are likely to have a higher demand in a NIT–saturated society.

The substitutionability of energy and information on the level of single tasks and goods is not easily visible on the level of economic sectors, since the main effect of NIT is to accelerate economic growth. Faster growth, is equivalent to accomplishing tasks, to producing and consuming goods and services in a shorter time. NIT can be regarded as more easily substituting information for time, rather than for energy[2]. This is the topic of the next subsection.

The above discussion of the relationship between information and energy concentrated on NIT. Other forms of information, such as other new technology, or more traditional wisdom, developed over centuries, or also knowledge about the future, will also very often show a substitutional relationship with the energy used to accomplish a given task.

1.3 Invetions for Saving and for Spending Time

A substitutional relationship between time and information is rather obvious in every day life. The less information is available the more time consuming trial and error is required to accomplish a task. Or if one knows exactly how to do something, how to get somewhere, one can do it in a shorter time, than if one had less information.

The purpose of technology very often can be seen as applying know–how (information) — and energy — systematically to tasks that are to be accomplished. According to Kowalski [7], the most important inventions can be classified in two groups, those that serve to save time and those that help spending that saved time most effectively. The first type will save working time or travelling time, i.e. the time of accomplishing a job. The second type of invention will improve the quality of the experience, such as providing a colour image on your TV instead of a black and white picture. The invention leads, in a way, to more consumption (three colours instead of just white) in the same time span. In that way both types of inventions generally lead to saving time, thus to a substitution of time by information in form of expertise and know–how.

Looking at the steady succession of inventions in spinning and weaving since 1760, the working hours per pound of yarn or per square foot of cloth were reduced thanks to these inventions and improvements by a factor of 1'000 [5]. Today's advances in further automation, by the rapid introduction of NIT in textile manufacturing is just a continuation of this process of substituting time with information.

The effect of NIT use on the energy demand at the level of the entire economy is too complex to quantify. But it follows from [5], that *the manner* of applying NIT is one of the most decisive influencing factors of future energy demand. The introduction of NIT can be a catalyst of development in two very different directions. One development is dominated by the substitution of time by information and characterized by much automation and robotics – also in the service sector –, a flood of cheap mass products and a high energy demand. In the other development NIT mainly serves the substitution of energy (and other resources) by information; NIT is then used to produce goods and provide services more precisely and more accurately, fitting individual demand. It is conceivable, that in a scenario, possibly somewhat utopian, in which the second substitution dominates, the energy demand does not increase, and impacts on the environment can be reduced in spite of considerable economic development and massive application of NIT. Thus Haggerty's vision is certainly a possibility. However, without a general change of peoples aspirations and policies, NIT will probably further growth more strongly than conservation: information is more readily used to save time rather than energy.

The limited availability of time may be one of the strongest felt limits in a persons life. Technology is employed to overcome this limit by packing more and more activity into the limited time span. This is done not only by speeding up the activities, but also by doing several tings at the same time, such as travelling and calling someone on the telephone; or eating and watching television; or working and listening to the radio. However, saving in this way time, as measured by a clock, one often feels rushed and senses a loss of time, as one subjectively perceives it.

2 Clock Time, Machine Time, Personal Time

In physics, time exists only in as far it can be measured, i.e. only in as far as some information is exchanged between objects, clocks and observers. Since many events take their course concurrently, an observer has to intervene to give these events a common time frame. Time, as one of the four coordinates in the time–space continuum, remains entirely empty without giving labels to events and relating them to an observer. In practice, time has to be related at least to the movement of a pendulum, the oscillation of a subatomic partical, or some such recurring event defined to serve as a clock. Time as used in physics can therefore be called clock time. In the natural sciences the passing of time is generally related to recurring events: astronomers use the movement of stars as their clocks, students of animals and plants the daily and yearly cycle and so on.

Time can further be specified by not only relating it to clocks, but to specific events. Already in the case of simple physics experiments, one speaks for instance of the time, an object takes to fall from a certain height. Thus specifying the process, for which the duration was measured. The difference between cocurrent events and coinciding events does not stem from their position in time, but from the meaning of the events for the observer. By giving meaning to the flow of information, that is necessary to observe time in the first place, time seems to take on special qualities [8].

On the engineering level, these special qualities are taken for granted: We identify time with a particular time for travelling from A to B, perhaps at a certain date, rather than with some abstract span of time. We often distinguish starting time, running time, idling time etc., times during which machines have different tasks. In economics and in every day life time is often a time related to a leisure time, working hours etc.

Time is very often also related to personal perception and may then be related to clock time only very loosely. Similarly time related to historical and societal events, although measured in days and years, has is own quality and laws that can not all be expressed in terms of clock time. The flow of time seem to slow down and speed up; the time can even be bright or it can be dark.

2.1 Working Hours and Leisure Time

Not only Marx, but many others, see leisure as a principal purpose of society. Leisure being not only the freedom from the treachery of work, but the source of renewed strength, happiness and well–being and an opportunity for personal development and fulfillment. From this view it seems only right that inventions are made to speed–up the working process and energy is spent on furthering leisure and that added energy use thus subsistute working hours [9].

In a more up–to–date view, leisure time is divided into two components: Time to consume, time for cultural development [10]. Blechmann argues that the two types of leisure time exclude each other (if they apply[3]).

Considering the very different energy intensity of cultural and other leisure activities, the type of leisure that society chooses has a large impact on energy and environment [5].

The pertinent substitutional relation between energy and time on a national level seems to be between that of energy use and the time it takes both to produce and to consume goods and services. Whether the time saved is simply used to produce and consume more, or whether some saved time is set aside as time for cultural development, is of prime importance.

Similarly, as one may question that simply the *duration* of leisure be a very decisive factor, one may question whether the quality of work is not more important for one's happiness than the duration of work, as measured in clock time. In a recent study [11] it was shown that the pace of life in 36 US cities, as measured by the walking speeds of postal clerks, by the speed of getting money changed at a bank teller etc., is more or less proportional to the incidence of heart disease in these cities.

Marx considered human labor to be the one and only valuable production factor. In that production factor he did not include time only, but he was also thinking of the effort, sweat and suffering involved. Capital he called "geronnene Arbeit", i.e. accumulated labor. The word "geronnen" evokes the image of solidified blood, that had been shed.

The problem is how to measure this all–inclusive time of work. By giving everybody the same wage, as conceived originally in Marxist economic systems, the hours spent are the principal input to the economy; as if it would not matter how much sweat and ingenuity is spent, in accomplishing a given task.

Even if time is not the only valuable input to the economic process it is instructive to considere the time input more explicitly. The author of this paper has explored the possibility of considering time, energy and information to be the only inputs to the economic process [5]. Some of this analysis is reproduced in the appendix.

In that analysis time is measured in working hours. As *one of these three* production factors, one can think of labor as containing components of all three: Time (hours on the job), energy (the little, often negligible bit of muscular energy) and information (the very important know–how of workers and employees).

Working hours, as a production function should be cumulated time, i.e. the total of all working hours that were required to produce something, including all work that went into processes preceding a given stage of production. Hannon et al. determined the cumulated working hours for the output of a number of economic sectors of the US economy [12]. This type of data measures time in such a way that could enable time to be used as a production function.

The examination of the relationship of time, energy and information on the level of economic activities, led to a method for computing the information content of goods and services. Although the method is based on the very bold and unproven assumption, that time, energy and information are the only input to economic activity, a preliminary test of that method yields plausible results [5]. It is conceivable that it would be worthwhile to explore economic activity more often having in mind, that time, energy and information are inputs of fundamental significance. This type of analysis is of particular interest, when one considers that the time input is readily associated with the employment provided, the energy input with environmental impact, and the information input with education, the level of technological development and the sophistication of organizational networks.

2.2 Productivity, a Sacred Goal?

Looking at the history of technology it seems that up to the industrial revolution in the second half of the eighteenth century, technical equipment was put in place primarily in immergency situations, when there was no other way to cope with the problem at hand. Wind and water mills were only used if and where there was a shortage of labor. The techniques employed had very poor efficiencies and these efficiencies remained more or less constant over centuries. Efficient wind and water mills were slowly developed in the eighteenth and nineteenth century, and satifactory models were only built at the end of the last century, not much before they became obsolete.

Also the steam engine was invented because of an emergency situation: people were freezing; the woods in the British Isles were runined from over–use and the idea of using coal proved difficult, because the open pits, from which the coal was mined, quickly filled with water and became useless. In this situation the steam engine, that could "raise water by the power of fire", was invented by Newcommen, a clever plomber. This machine was so inefficient, that it could only be used in a coal mine, where ther was no shortage of coal.

Half a century after Newcommen the full–time teaching assistant, Watt, started to play with this engine and thought of ways to improve it. It was the start of a new aera in two ways: the start of the industrial revolution and, not unrelated at all, the start of engineers routinely working at improving the efficiency of machines and installations.

The improvment of the efficiency of the steam engine had a doubble effect on the possibility of it's use. It became cheaper to run and thus could be employed not only in may more coal mines (in smaller coal mines the water pumps had previously been driven by horses), but more imporantly, the steam engine could also be applied in factories. With further development and specialization steam engines also started to power rail roads and boats. The industrial revolution was the result of a positive feel–back loop: steam engines and rail roads required steel, the steel industry required coal, coal mines and coal transport required steam engines and so forth.

Engineers optimize production in terms of their resource requirement and in terms of clock time. Time optimization is very similar to the general notion of productivity and is particularly important, since the economic systems selects the most productive systems. Although resource optimization should lead to the more sparing use of resources, it leads to the possibility of — and usually in fact to — more wide spread application of particular machines and processes. In conjunction with the speeding up of processes the engineer's optimization thus leads to economic growth — and usually to an increased use of resources.

Technology's role in speeding up the economic process and the use of the natural environment has to be seen as a mixed blessing. Limits to this speed up will be difficult to impose without big losses of efficiency, but they are needed never the less.

2.3 Freedom from the Tyranny of Time

Technology and personal time interact in a contradictory manner.

On the one hand, as we have seen, technology's purpose is to a large extent, the freeing people from the tyranny of time. Technology shortens working hours and lengthens life expectancy, it allows us to eat stawberries all year, look younger, be here and there and enjoy several things at the same time.

On the other hand, the increased importance of technology in peoples lifes means also the increased subjection to the relentless dicate of machine time. Today's life of the average person in an industrialized country consists of running from one meeting or job to an other, doing this and that "in time" and worring constantly about missing out on this of that irretrievable event.

The other papers in this commitee have much more to say on the relationship of personal time to cultural development. But the proper use of technology has much to do with culture, with an organic integration of technology in the cultural environment. This has also a lot to do with time. Rapid changes in technology and comparatively slow cultural development tend to endanger this integration.

The engineer's progress tends to be too fast in respect of the general cultural development and often too slow in respect of the demands of economic competition. If economic growth is faster than technological progress, one runs into the danger of not allowing the application of a technology to grow hand in hand with it's development and wasting energy (and otehr ressources) by implimenting prematurely inefficient processes.

Much depends on the proper attention to information: communication facilities, possibly serving as a buffer between personal time and machine time; widely distributed technical know–how, keeping technology under the control of the users; and proper organizational net–works are all important. But more important is education in the broadest possible meaning. For technology to contribute to the freeing of people from the tryranny of time, it is necessary to pay much attention to the arts and humanities, to social and political questions etc., etc. — in short to the entire cultural development.

3 Shifting meaning

3.1 Professions and Definitions

In this paper some of the relationships of time, energy and information were touched upon, primarily in three areas of scientific thought: in the area of physics, i.e. of idealized models of our physical environment; in the area of engineering, i.e. of descriptions of machines dedicated to particular tasks; and in the area of economics, i.e. of national accounts and models of production and consumption.

Every discipline has it's own language and the definition of terms is an essential part of each discipline. Physics, for instance, does not claim to describe the real world, but only deals with models, that represent a particular aspect, observable in the physical environment. Often the terms in the language of physicists are not defined just in themselves, but in relation to each other. What is more, in modern physics the quantities always relate to an observer, i.e. the observer is part of all models.

Energy is a term used practically in all disciplines, both in the "hard" sciences (Naturwissenschaften) and the liberal arts (Geisteswissenschaften).

In physics the term energy has only been used widely — and distinguished from the term force — since the middle of the 19^{th} century. It is a collective term for mechanical energy (contained in the movement of a body or represented in the work it took to bring a body into a position away from an equilibrium), thermal energy (heat accumulated in some body), chemical, electro-magnetical and nuclear energy. Mechanical, thermal, electrical energy are much more readily understood separately, than as a collective entity.

The collective term could only be introduced into physics after the first law of thermodynamics was phrased, saying these various quantities were all the same. One of the two discoverers of the first law of thermodynamics was Robert Mayer, a young medical doctor, who was primarily thinking of metabolizable energy, muscular energy and blood chemistry. He made his discovery through a semi–spiritualistic experience on a ship journey to the East.

But today a physicist, after having gone through his training will probably think that energy is a physics term and that in other walks of life, the term is just borrowed. Energy is an integral part of the physics disciple, with innumerable relationships to other terms like force, speed, power, etc. The sum of these relationships is what physics is all about and it is hard to imagine that energy is more than what energy is in physics.

But of course energy has it's own definitions in statistics, in economics and is also used in fields like yoga, bio–energetics and many more.

Very beautiful is the poetic definition of energy by William Blake (1757–1827) in the second of the following two verses:

> Man has no body distinct from his soul:
> For that called body is a portion
> Of soul
> Discerned by the five senses
> The chief
> Inlets of soul in this age.
>
> Energy is the only life
> And is
> From the body;
> And reason is the bound
> Or outward circumference of energy.
> Energy is eternal delight.

Note for instance, how close Blake is in the fourth and fifth line of the second verse to what was said above about the role of information in energy conservation.

A fairly large body of literature exists on the different perceptions of time in the various sciences [13] [14]. Time is a very elusive term, even in physics [8]. One of many problems is perhaps that today we call time both what the Greeks called chronos and what they called chairos. Chronos is the relentless flow, which Newton saw as follows: "Absolute, true and mathematical time, of itself, and from its own nature, flows equably without relation to anything external, and by another name is called duration". Chairos has little to do with clocks; it has to do with the right time to do or to experience something; as the Bible says: "There is a time for joy and a time for sorrow, a time for laughter, a time for tears ..."

Another fundamental distinction is that between linear and cyclic view of time. Even in the sciences the two views are common. In physics, time is usually seen to be linear. But in the life–sciences the cyclic aspect is of prime importance.

Finally, information also has different definitions in different sciences. There is, for instance, a remarkable change in the meaning of "information" when going from the statistical definition used in early theory of communication to *selective information* as used in more recent information theory. Some social scientists like to make a distinction between information and knowledge, where knowledge results presumably from a further selection procedure from a large body of information. The Romans who coined the word, used it both in the sense we use it today in the everyday language, i.e. of transmitting a message to a receiver, and also of education, i.e. the *formation* of the mind.

3.2 Measurability and Value

It is perhaps possible to rank–order the sciences according to two scales: their interest in dealing with quantities that are either exactly measurable, or with quantities that are expressing value. On the first scale, physics is perhaps at the top, followed by the other natural sciences, engineering, statistics, economics, the humanities, philosophy and religion. On the other scale, the order is reversed: first are the prophets, last the value–free physicists.

Considering the various sciences from physics to religion and their definitions of the three terms time, energy and information, the shifting emphasis from measurability to value is striking.

Even within physics a slight shift can be detected, namely from the main areas to thermodynamics[4]. In thermodynamics, mechanical energy is somehow *better* than thermal energy, a concept totally foreign to the rest of physics. And, not unrelated to this, entropy has an antropocentric touch: for instance, when mixing oil and water (using an oil that will not later coalesce by itself) and making the oil droplets smaller and smaller, it depends on the observer's power of observation, to decide when the two substances are mixed and the entropy thus has increased. These considerations, foreign to pure physics, also give time its direction. Time is not anymore, like in mechanics, a coordinate, but it runs it's course.

In engineering, value judgements play a significant role, because efficiency is of prime importance. A machine that can do a certain job with less energy, in a shorter time, or with fewer instructions is better than the competing model. Similarly, not all energy is valued in the same way. The thermal energy in the air mass of an over–heated room is not concidered a valuable form of energy. The energy content of tar–sand in an inaccessible location is less valuable to an engineer, than the same energy content in readily available, clean natural gas. Machines and their inputs are measured in terms of their usefulness in performing given tasks. A certain, manageable amount of uncertainty enters the determination of that usefulness.

In economics the desire to valuate and to quantify are about equally strong. In fact valuation means to give a price–tag to goods and services and thus is synonymous to quantification and measurement. Valuation is generally done by the market and economists study that mechanism.

As we go on to the liberal arts or even on to philosophy and religion, attaching value to phenomena becomes more and more important and the quantification becomes unimportant or often probably also irrelevant or unthinkable.

Related to the increased attention to values, when going from the hard to the sorter sciences, is an increased interrelatednes and relevance of phenomena to human experiance. As the physicist Dürr says, accuracy is achieved always at the cost of relevance [15].

All three terms, time, energy and information, undergo a transition from the hard to the less hard sciences. The transition is sometimes gradual, but often also abrupt. They change in meaning and definition. Besides the names, it is difficult to say what remains unchanged.

3.3 Unity and Diversity

It is fashionable to use terms of one discipline in another discipline. One example is the use of entropy in economics. When are these cross–disciplinary endeavours enriching and when do they only add confusion?

The difference is, whether one borrows terms or whether concepts are transposed. Of course it is a high art to find instances, where concepts can be applied across the boundary of disciplines. To do this one has to have a deep understanding of both disciplines. It is the best way of working towards the high and important goal of the unity of science, and of not betraying the diverse spirit and tradition in the various sciences.

This paper is an inter-disciplinary discussion of the three fundamental quantities time, energy and information by someone educated to as a physicist, who now works in engineering and has a strong interest in economics. A few interesting points emerge:

- In considering energy conservation, time is an important element that should not be neglected.
- In many instances, particularly in parts of physics and engineering and often economics, time, energy and information can be regarded as substitutable for each other.
- The introduction of new information technology, NIT, is a principal determinant of future energy use. NIT can either substitute time, thus leading us to a society of harried mass consumers, or substitue energy and enable an increase in the quality life without adding stress to the environment.
- In future economic research, it is perhaps useful to considere time, energy and information as production factors.

It would of course be interesting to pursue the discussion further into other disciplines. One would have brilliant examples to follow: For instance, Teillhard de Chardin's world view is a remarkably ingenious application of the Minkowski–cone[5] to religion. He places the center of the figure, the center of attention, away from present–day man into the distant future, a point where everything, also all time, energy and information come together, calls that point Ω, or Good, and thus draws an image for his belief, that everything is bound to converge towards this force.

Similarly it would be fascinating to explore intercultural changes in the relationship of time, energy and information, such as the fundamental difference of Teillhard de Chardin's Ω–point and the goal of experiencing energy– and information–free time in some Eastern religion. The title of this ICUS–committee would have suggested doing that.

However, the author of this paper would most likely have fallen into the trap of stealing terms in one area of thought and using them in another area, without fully grasping the underlying concepts. This would in no way add to the unification of the sciences and areas of thought, without destroying their immense and beautiful diversity.

Notes

1. Title of Section 1 is very similar to a title used by Kirk Smith [3].

2. R. Kümmel and W. Srassl in [6] came to a similar conclusion by analyzing economic parameters. [6] contains also interesting papers regarding the substitutability of time and energy.

3. Blechmann mentions sport as an activity that does not fit the two categories. Generally leisure also has the function of compensating for one–sided use of a person's gifts during working hours.

4. A strange branch of physics, that was not developed by physicists anyway! Carnot, who discovered the second law of thermodynamics, was an engineer, interested in measuring the performance of machines.

5. The Minkowski–cone, a concept of modern physics, contains all points in a space–time diagram, that a person can ever reach in the future, the only restriction being, that the person cannot travel faster than the speed of light.

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