1 Preliminaries

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1.1 Summary

This is an introductory chapter. We present first a short comparison of the problem of knowledge and technology creation versus the problem of knowledge justification and technology validation and verification. We give a very condensed review of the history of epistemological knowledge justification theories and approaches. Then we characterize novel approaches, new *micro-theories* of knowledge and technology creation that emerged in the last decade of the 20th Century and in the beginning years of the 21st. We interpret them as one of the signs of the beginning of a new informational and knowledge civilization era; main megatrends of this era are listed. The last of them – the intellectual *megatrend of mental challenges, of changing the way of perceiving the world* – is related to the need for understanding diverse new concepts. We stress several such concepts, but perhaps most important is the change from the *principle of reduction,* typical of philosophy in the 19th and 20th Centuries, to the *principle of emergence* of essentially independent, irreducible, thus in a sense transcendental concepts on new levels of complexity. We also stress that such a principle is not only observed empirically in biology in punctuated evolution, not only results rationally from mathematical theories of deterministic chaos and complexity, but also emerges practically from coping with complexity in modern computer networks. We finish this chapter by briefly outlining new challenges to epistemology, particularly in view of demands of computational intelligence, and the contents of this book.

1.2 The Problem of Knowledge and Technology Creation Versus the Problem of Their Justification and Verification

Historically there have been many and diverse attempts to understand how knowledge is created. Generally, until the last decade of the 20th Century we could distinguish two main schools of thinking.

The first maintained that knowledge creation is essentially different from knowledge justification and validation - thus distinguishing *context of discovery* and *context of justification*. This school also maintained that creative abilities are irrational, intuitive, instinctive, subconscious. This view was represented by many great thinkers of very diverse philosophical persuasions and disciplinary specialities. Nietzsche, Bergson, Poincare, Brouwer, Einstein, Heisenberg, Bohr, Freud, Jung, Gödel, Popper, Kuhn, Polanyi – we could continue with a much longer list – were all convinced of this way of characterizing creative abilities. Naturally, each of them stressed slightly or even essentially different aspects of this general view. Nietzsche believed in dominating role of irrational human will; Bergson – see (Bergson 1903) – stressed the creative role of intuition, but understood it as an irrational, mystic force. Poincare – see (Poincare 1913) – stressed the role of *illumination* or *enlightenment* in a creative process; Brouwer and Gödel – each for a different reason – believed that all mathematics is based on intuition. Einstein, Heisenberg, Bohr – all stressed diverse irrational aspects of creative acts. Freud explained creativity by subconscious instincts, Jung by myths in the *collective unconscious*. Popper – see (Popper 1934) – underlined logically the earlier conclusion of Hume that physical induction gives no guarantee of truth (as opposed to mathematical complete induction, which might be a valid method of proof) and thus postulated that new theories, obtained by irrational creativity, should be subject to falsification tests. Kuhn – see (Kuhn 1970) – denied the possibility and rationality of falsification, but admitted that the new concepts that form the basis of a scientific revolution result from creative, irrational acts; we shall comment in more detail on this distinction in the following chapters. Selye (Selye 1964) stressed the role of vision and intuition. Polanyi (Polanyi 1966) described creativity as the result of personal, tacit knowledge which contains instincts, myths and intuition. At the end of the 20th Century, this view was theoretically supported by sociology in *soft and critical systems theory* (see e.g., Jackson, 1998 and Midgley, 2003) and even empirically supported by the results of experiments performed by brothers H. and S. Dreyfus (see Dreyfus et al. 1984), but their anti-paradigmatic book *Mind over Machine,* aimed against the concept of artificial intelligence, was not understood by a broad audience.

The second stream kept to the old interpretations of science as a result of empirical experience, induction and logics, thus heavily criticised Popper and refused to see creative acts as irrational. This view, represented by many hard scientists, is particularly popular in the English-speaking world, perhaps because of the English tradition of empiricism. This might be also related to the unfortunate property of the English language that understands the word *science* originally only in the sense of the *hard sciences,* excluding *technology,* but also excluding *soft and human sciences* – sociology, economics, law, history etc. Other languages – such as German, Polish, and Japanese – understand the word *science* more broadly, and speakers of these languages are thus more prepared to accept the opinion that creative acts are irrational. In fact, Japanese are so much acquainted with the use of intuition that they protest calling it irrational; it is much more an *a-rational* ability to them.

Nevertheless, the opinion that science is the result of inductive reasoning and that creative acts can be perfectly logically explained has been long represented in many publications, particularly by representatives of the hard sciences. Such theory can be rationalized by maintaining that there is no distinction between the context of discovery and the context of justification or validation, that there is only a joint creative process that can be perfectly logically planned, that intuition is only all accumulated experience and illumination is only a revision of hidden assumptions. See the change of opinions by Root-Bernstein, who in one of his books (Root-Bernstein 1989) demands a logical explanation of creativity and refuses to recognize a-rational creative abilities, but who then stresses their importance in later publications, see, e.g., (Root-Bernstein 2002), which is also one of the signs of the revolutionary, paradigmatic change. This change, however, is characterized by a synthesis of the two opposite opinions about sources of scientific creativity, by a third, integrated opinion presented in this book:

We stress that creativity uses a-rational abilities of the human mind, but we try to rationally explain and analyze these a-rational abilities.

While accumulated experience is an important factor of intuition and a revision of hidden assumptions often leads to illumination, these factors are not the sole and unique characteristics of creativity, as we show in Chapter 2.

Moreover, the representatives of hard sciences addicted to the opinion that science is the result of inductive reasoning tend also to negate the importance of technology as a field of human creativity. We shall discuss this opinion in more detail in Chapter 3; here it is sufficient to present our opinion in brief. Experience in creating technology – inventing and patenting new technological devices or constructing large technological systems – combined with experience in mathematical creativity – inventing and proving new theorems – has convinced us that:

> Technology creation differs from other kinds of scientific creation only in that it is focused on solving practical problems, creating knowledge as a by-product.

Designing a new house is a creative activity; so is developing a new mobile telecommunication device. Moreover, technology creation still retains some connotations of the old Greek word *techne,* meaning craftsmanship and art. Actually, the main motivation of a technologist at work is *creative joy* – the satisfaction of well done design and construction. At the beginnings of the new informational and knowledge civilization age, creating new *incremental* knowledge, including new technology variants, is also essential for the functioning of the market economy – see (Stehr 2002). On the other hand, basic scientific advancements can be observed in technology as well as in hard sciences: we shall show later that the current development of new ways to record the heritage of human civilization might be equally important as Gutenberg's discovery (or rediscovery) of print.

Both in creating science and in creating technology there are traditional ways to justify, validate or verify postulated results, constructions, and devices. The context of justification does rely on logic and has a very long history.

1.3 Short Review of the History of Knowledge Justification and Verification Approaches

Knowledge justification and validation is the main subject of the philosophic discipline called epistemology. Most accounts of the history of epistemology start with the *Dialogs* (ca. 380 BC) of Plato, who first postulated the existence of *rational ideas a priori given* to the human mind, thus forming Platonian *rationalism,* as opposed to the various types of *empiricism* that already existed at that time among Greek philosophers. However, it must be stressed that much of Plato's writings described discussions with his teacher, Socrates, who actually created another basic philosophic concept – the *dialectics,* the art of discourse which is the surest way of arriving at philosophic (we would say today scientific) truth. Already at that time, we can identify the basic elements of a dialectic process, the *dialectic triad: thesis – antithesis – synthesis,* formalized much later by the basic philosopher of dialectics, Hegel. Thus, dialectics as a practical method preceded both its theoretical analysis and its main application: the dialectic dispute between empiricism and rationalism that through many centuries found repeated synthesis (first given, e.g., by Aristotle), new thesis and antithesis, and again a new synthesis – because the dialectic spiral can go on without end. This does not mean that the resulting process is *cyclic* – it is much rather *chaotic,* since synthesis is a creative act.

Without understanding the dialectic method, other cultures in the world will not fully understand European culture. The term 'European' does not include all Occidental culture. For example, American culture stresses *competition* between various trends of thought rather than the *dialectic triad.* Thus, in American accounts of Western philosophy we would read that the continental European school founded by Descartes formulated the basis of modern rationalism by separating the intellectual, spiritual concept of the *knowing subject*[1] from the empirical, material aspects of the human body; that this was challenged by the British school of empiricists, notably by Locke, and that the competition of these schools is observed until today despite many attempts at a synthesis – say, by Kant, Hegel, Marx. However, this is a great simplification. In fact, in his basic monograph *Kritik der reinen Vernunft* (Kant 1781) he gave another – after Aristotle and St. Thomas Aquinas - great synthesis of these two streams of thinking, and the history of philosophy after Kant in a sense started anew. Though both Hegel and Marx were dialecticians, Hegel's idealism was countered by the materialism of Marx – another example of thesis and antithesis. A synthesis was actually given (though not necessarily recognized) by Americans, in the *Pragmatism* (James 1907).

The 20th Century was characterised by a new thesis – by the *logical empiricism* of (Russell 1912) and (Wittgenstein 1922) – of the *Wiener Kreis* which for many philosophers, including Ayer, Popper, Kuhn, and Quine, defined a background even if most of them exceeded the rather narrow confines of this direction. Equally strong was the antithesis, of *humanistic rationalism,* represented by e.g., (Husserl 1913), (Heidegger

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[1] For readers not acquainted with philosophical terms we recall that *knowing subject* means an individual human trying to comprehend *objects of study* in the surrounding world. This meaning is quite different from *subjects of study*, equivalent to themes of study.

1929), by *existentialism* and later by (Gadamer 1960). A new synthesis was given by Quine already in 1953 – this time not in a great monograph, but in a small paper, *Two Dogmas of Empiricism,* (Quine 1953). A great logician, Quine argued that two basic axioms of empiricism are actually not logically consistent and that we must accept what could be called *mild empiricism and constructivism:* all knowledge is constructed by the human mind (which is rationalism and constructivism) but it touches empirical experience only as boundary conditions (which is mild empiricism). Later, (Quine 1969) added a neurophysiologic model of cognition, a biologically based rationalism and constructivism.

In parallel, another dialectic thesis and antithesis were formed, in the *falsificationism* of (Popper 1934) versus *historicism* – which can be diversely understood, including e.g., Marxian tradition, but is also related to the concepts of *paradigm* and *scientific revolution* of (Kuhn 1962). Later, epistemology concentrated mostly on the *theories of historical change* in science, continuing the discussion of *paradigms* versus *falsificationism* started by Kuhn and Popper. Seeking for a synthesis, diverse modifications of the concept of *paradigm* were proposed – the concept of *research program* in (Lakatos 1970), the concepts of *science as a problem solving activity*[2] and of *research tradition* in (Laudan 1977), see, also (Gutting 1984). These theories of scientific change are also *theories of knowledge creation,* but on a grand *macro-historical scale,* not concentrating on the details of *micro-creation of knowledge and technology,* of solving a scientific or technical problem.

At the end of the 20th Century, together with the emergence of knowledge-based economy, the economic demand resulted in the need of a better understanding of creative processes, *of micro-theories of knowledge and technology creation.* In this book, we rely on the theories of historical scientific change, *but we speak about a new scientific revolution* that concentrates on *the understanding of detailed mechanisms of creative processes, needed today and tomorrow for knowledge economy and informational society.*

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[2] In our opinion, although most science and, in particular, technology is a *problem solving activity,* not all science can be characterized this way. Parts of science, today even parts of technology, are devoted to *finding new perspectives.* In the question of *revolutions* versus *evolution of scientific change,* we believe in the *punctuated evolution,* thus including some phenomena called *revolutions.* We also should warn that the word *paradigm* is often used in this book in its broad popular sense, characteristic, e.g., for today sociological use, while the original sense used by Kuhn was more specific, actually applicable to physics.

We shall discuss these concepts in more detail and give an attempt at a synthesis in Chapter 2.

During these disputes, it was also shown that we must modify our understanding of the concept of knowledge. The old Platonian definition that *knowledge is a justified true belief* was shown to be logically inconsistent, see (Gettier 1973). It also turned out that *knowledge* is a concept so rich in meaning that any single crisp definition of this concept is bound to be misleading. We shall discuss diverse possible meanings of the concept of *knowledge* in Chapter 3.

Actually, at the end of 20th Century not one, but several new theses were developed; and again we can find in them a dialectic opposition, this time concerning the concept and importance of truth. One thesis took the form of radical biological constructivism (e.g. Maturana 1979, von Foerster 1973): if all of knowledge is constructed by the human mind as a result of biological evolution, then the concept of truth is not necessary. This radical constructivism was in a sense supported by radical relativism, starting with radical sociology, mainly by the *strong program of the Edinburgh school* – see, e.g., (Barnes 1974) and (Bloor 1976), also by *post-existentialism* and *postmodernism.* Precisely opposite was a further development of humanistic rationalism: (Gadamer 1960) stressed the value of truth as an essence of human self-realisation. Another, similar trend can also be observed in humanistic sociology, represented by Marcuse – see (Marcuse 1964) and by Habermas (Habermas 1974), with the former's concept of the *single-dimensional man.* The antithesis of this is the concept of the *multidimensional knowing subject* (Czarnocka 2003). A new challenge came from the dispute between *modernism* – with the great synthesis of Habermas (Habermas 1987) – and the *postmodernism* (Foucault 1972), (Derrida 1974), (Lyotard 1984).

All these disputes were mostly concentrated on human communication and language, as was most philosophy of the 20th Century. They were also essentially reductionist, trying to explain or even deny the importance of more complex concepts by the analysis of more primitive concepts. We shall show in this book that there are at least two reasons for a change of this concentration today, at the beginning of a new era of civilization:

1) Language is just an imprecise code to describe a much more complex reality;
2) The principle of reduction, typical of philosophy in the 20th Century, must be replaced with the principle of the emergence of essentially independent, irreducible, and thus in a sense transcendental concepts at new levels of complexity.

Concerning 1) one can ask: *if words are inadequate to describe anything, why do you write this book?* The answer is that we, humans, have built all civilization by communicating and using words; but we should recognize and critically analyze both the importance and the limitations of using language.

Concerning 2) one can ask: *what are essential examples of such irreducible concepts?* We believe that such examples are, between others, the concepts of *truth* and *objectivity.* Until now, there has been no valid synthesis of opinions on the question of why the concepts of objectivity and truth are needed along with the concepts of intersubjectivity and relativity; we present our opinion about this question in several further chapters, after discussing a rational theory of intuition.

This has been a short presentation of the tradition of epistemology from the Western, Occidental side, stressing a European point of view and the role of dialectics in philosophy. Oriental, Eastern – in particular Japanese – tradition is quite different. Without giving a historical review of this tradition, several facts should be stressed.

The Oriental, Far East philosophy – be it Confucian or Buddhist or Shinto unity with nature - stresses the ideal of *harmony*. Thus representatives of Far East cultures positively value synthesis, but dislike the dialectic counter-position of thesis and antithesis; they are not good at scientific discourse, preferring to concentrate on achieving consensus. However, a consensus achieved too soon is usually shallow; it might have great social or political value, but lacks deep scientific value. Thus, the best advice a representative of European culture can give to Japanese is following: *teach and cultivate scientific debate, learn dialectics, repeat recursively thesis – antithesis – synthesis* – and you will that way accelerate the development not only of your basic sciences, but also of your basic technology.

On the other hand, the Japanese culture has influenced Western philosophy and epistemology, both historically and recently. Historically, the Far East concept of the unity of mind and body has influenced Western thinkers, for example Nietzsche, also Freud and Jung. The concept that we realise our ego by *being,* by *becoming,* is originally from the Far East, though Westerners attribute it to Nietzsche and Heidegger (the latter took it from the former, but it is known that the former was influenced by Oriental thinking). Recently, knowledge creation theories in the world were influenced essentially by two concepts of distinctly Japanese provenience: *intuition and group collaboration.*

There is no doubt that Japanese culture relies much more on intuition than Western culture. There might be several reasons for this, the simplest being that the structure of Japanese grammar leaves a large part of understanding to the context of discussion – and thus not necessarily to logic, but rather to the intuition of the interlocutor; another reason is the pictorial character of the kanji writing system. There are also deeper cultural reasons for the importance of intuition and emotions to Japanese that will be discussed in Chapters 2 and 6.

There is also no doubt that Japanese culture stresses group collaboration much more than Western culture – again for many historical, anthropological and sociological reasons, one of them being the importance attached to harmony and consensus. In Western approaches, the social dimension is typically analyzed by counter-posing the individual and the society;[3] for a Japanese, the group is ontologically just as important as the individual, if not more so. Whatever the reasons, since the last decade of 20th Century the concepts of intuition and of group collaboration have resulted in novel approaches to knowledge creation, most directly or indirectly related to Japanese origins.

1.4 New Approaches to the Problem of Knowledge and Technology Creation

Historically, the first of such approaches is *Shinayakana Systems Approach* by Sawaragi and Nakamori, with first publications in (Sawaragi and Nakamori 1990, 1992), in the field of decision and systems science. Being systemic and influenced by the soft and critical systems tradition, it did not specify a process-like, algorithmic recipe for knowledge and technology creation, only a set of principles for systemic problem-solving.[4] To these principles belong: using intuition, keeping an open mind, trying diverse approaches and perspectives, being adaptive and ready to learn from mistakes, and being elastic like a willow but sharp as a sword - in short, *shinayakana*.

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[3] With the exception of *brainstorming,* on which we comment later, and some recent works in sociology of science, see e.g. (Fuchs 1992). However, it is doubtful whether science creation can be reduced to the interdependence of group members and to the resources at the group disposal, as suggested by such works.

[4] Being only an observer, Andrzej P. Wierzbicki can testify that both Yohikazu Sawaragi and Yoshiteru Nakamori had also experience in constructing algorithmic procedures, but have chosen to propose *Shinayakana Systems Approach* as an open set of principles, in order to preserve its *shinayakana* (elastic like a willow, sharp as a sword) character.

In parallel, in a different discipline – management science – another approach was developed by Nonaka in 1992, with an international publication in the book *Knowledge Creating Company* (Nonaka and Takeuchi 1995). This is the now-renowned *SECI Spiral,* with its process- and algorithmic-like[5] principle of organisational knowledge creation. This principle is revolutionary because it stresses steps leading to knowledge increase surely (even if the increase might be small), based on the collaboration of a group in knowledge creation and on the rational use of irrational (or a-rational to a Japanese) mind capabilities, namely tacit knowledge, which consists of emotions and intuition. The *SECI Spiral* results from four consecutive transitions between four nodes on two axes. One is called the *epistemological dimension,* counter posing *tacit* and *explicit knowledge;* the other was originally called the *ontological dimension* (not very fortunately; also tacit and explicit knowledge are ontological elements of discourse, hence we shall instead use the name *social dimension*), which counter poses *individual* and *group.* The transition[6] from individual tacit knowledge to group tacit knowledge is called *Socialization;* the transition from group tacit to group explicit – *Externalization;* the transition from group explicit to individual explicit – *Combination;* the transition from individual explicit to individual tacit – *Internalisation.* Upon completing these four transitions, the knowledge is increased, and continues to increase after each new cycle, hence *SECI Spiral*.

But the problem of rationally using irrational or a-rational mind abilities was perceived at this time by other researchers as well. Wierzbicki, who observed and was much influenced by the formation of *Shinayakana Systems Approach* while spending a year at Kyoto University in 1990, published the *Rational Theory of Intuition* in (Wierzbicki 1992) as a

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[5] Here we should clarify that by *algorithmic-like principle* we mean a procedure with defined steps or stages (here called *transitions*), even if some of these stages allow diverse interpretations and the procedure can start from diverse initial stages. The procedure might form a *spiral* if it is iterative and returns to initial point with increased parameters (here – increased knowledge). *SECI Spiral* is in a sense (we discuss it later) similar to an older process of Western origin, *brainstorming,* but the latter was not characterized as a spiral until recently.

[6] Originally called *conversion,* but this term implies using up a converted resource, while knowledge cannot be diminished by usage. Therefore, we use here a more neutral word *transition,* which means going from one node to another or shifting attention.

working paper at IIASA[7] and in (Wierzbicki 1997) as an international journal article. This theory does not claim that intuition is a rational ability of mind, but that it can be explained rationally using modern knowledge of telecommunications and other informational sciences as a *preverbal* ability to remember and reason, and that this explanation can be used for empirical tests (thus, it follows essentially the Quinian rational constructivism and mild empiricism). We shall present this theory in more detail and extend it in Chapter 2, further using it in combination with the *SECI Spiral* as a basis of constructing the *Creative Space.*

Almost at the same time, another more basic theory of knowledge creation came directly from philosophy. Motycka – see (Motycka 1998) – in Poland[8] proposed another theory: that of basic knowledge creation in times of a crisis preceding a scientific revolution. This is actually a historical *macro-theory* of knowledge creation, but we shall later show that it can as well be interpreted and used as a *micro-theory*. Motycka also used the irrational abilities of the human mind – mostly *instincts and myths,* namely the concept of *collective unconscious* (Jung 1953), and also intuition. She postulates that, in times of a crisis of a basic science, scientists use a *regression* to myths and instincts in order to stimulate novel approaches to their field of science.

These two Polish approaches were developed independently from the *SECI Spiral,* though they were influenced by the Japanese tradition – Wierzbicki directly by *Shinayakana Systems Approach,* Motycka indirectly by Jung. However, a few years after the international publication of *Knowledge Creating Company,* several approaches directly stimulated by this book were also published, including several papers presented, e.g., at the 37th Hawaiian International Conference on Systems Science in Hawaii in 2004. We shall mention here only one of them (Gasson 2004), who observed that in order to mobilize the distributed individual knowledge of employees, a Western company would use a process very much resembling the *SECI Spiral* but moving in just opposite direction.

Further development of the *Shinayakana Systems Approach* was given in (Nakamori 2000), in a systemic and process-like approach to knowledge creation called I^5 *System* or *Pentagram System.* The five ontological elements of this system are *Intelligence* (and existing scientific knowledge), *Involvement* (and social motivation), *Imagination* (and other aspects of creativity), *Intervention* (and the will to solve problems), and *Integration* (using systemic knowledge). True to the Shinayakana tradition,

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[8] Alina Motycka is the head of Epistemology Department of the Institute of Philosophy and Sociology of Polish Academy of Sciences in Warsaw.

there is no algorithmic recipe for how to move between these ontological nodes: all transitions are equally advisable, according to individual needs. Thus, *I^5 System* stresses the need to move freely between diverse dimensions of creative space; we shall discuss these concepts in further chapters.

There is no doubt that since the beginning of the last decade of 20th Century, many approaches were developed stressing and rationalizing the need to use the irrational abilities of the human mind in creative processes. It is, as we indicated earlier, a scientific revolution. It is motivated by the need of a better understanding knowledge and technology creation processes, of analysing their patterns in order to use these patterns as exemplars for future action and to support such processes by *computational intelligence,* in times of *knowledge economy.* However, we also interpret it as one of the signs of the beginning of a *new informational and knowledge civilization era.*

1.5 The Challenge of New Informational and Knowledge Civilization Era

The new civilization era of information and knowledge-based economy started around 1980. It is a historical era of long duration – in the sense of Braudel, see (Braudel 1979), characterized by a new way of understanding the world. This understanding is *systemic, dynamic, chaotic, and assumes the emergence* of qualitatively new properties of complex systems which cannot be reduced to the properties of system components; we shall discuss this understanding in more detail in the next section and in further chapters.

There are various perceptions, diagnoses and concepts that describe the current *global informational revolution*, but it is generally accepted that the new *global information infrastructure* will gradually result in a *knowledge-based economy* and an *information society* or even in a *networked informational civilization*. Actually, the concept of the information society is the oldest, starting in Japan over 30 years ago; but it was about 10 years ago adopted by European Union in response to the concept of a global information infrastructure promoted by United States. OECD tried to combine both these concepts by advancing the notion of a *knowledge-based economy*. The monumental work of Castells (Castells 2000) used the concepts of *information age, informational civilization* and *networked society*. Castells rightly argues that we should use the term *informational society* rather than *information society.* On the other hand, we can argue that together the informational society and knowledge based economy constitute a new *knowledge civilization era.*

Knowledge civilization is a long duration historical structure in the sense of Braudel, who argued that such structure is a historical era in which basic ways of understanding the world are relatively stable. As an example he used the era 1440-1760 as a long duration historical structure preceding the formation of capitalism and industrial civilization, where the date 1440 corresponds roughly to the discovery (or rediscovery[9]) of print by Gutenberg. Industrial civilization lasted approximately from 1760 until 1980, and informational civilization will probably last from 1980 until the end of 21st Century, see (Wierzbicki 1988, 2000, 2004) and Chapter 5. The date 1760, universally accepted as the beginning of industrial civilization, did not mark the new discovery of the steam engine, only an improvement of an older discovery – Watt added an automatic control system of rotation speed to the previously known (and used in mining in Wales) steam engine, which made the device safe and thus broadly usable.

The date 1980 might be taken as the beginning of informational civilization because just before that date personal computers were developed and broad civilian applications of first computer networks and their protocols were implemented, combining two older discoveries – telephone networks and computers – and thus making possible the wide social use of information technology. The long duration of such a civilization eras is interpreted as the result of a long civilization delay – the time needed before a fundamentally new concept (such as the concept of cellular telephony, developed since the 1940s, or of deterministic chaos, developed since the 1960s) is universally understood, accepted and utilized. Using stability theory, one can prove (see Chapter 5) that the duration of such a long era should correspond to four times the civilization delay. Since now the civilization delay amounts to around 40 years (the concepts of chaos, of cellular telephony, of digital television all indicate such a delay) but is shortening, we can estimate that informational civilization will last for at least 120 years.

For all the diverse interpretations and approaches to the current informational revolution, there is also a common basis. There is no doubt that *information and knowledge are becoming essential economic assets*

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[9] Commercial contacts of Europe with China were rather intense long before Gutenberg, thus we cannot say with certainty whether his invention was fully independent. However, his invention was certainly much more technologically advanced than Chinese printing and enabled the broad social use of books in Europe; a broad social use of books in Asia using Chinese characters was technically much more difficult and came much later.

with either a private or public character and that it is necessary to develop either rules for their sharing or business models for their selling and exchange. However, not many people fully understand the informational and knowledge civilization, many see only its technological aspects or are afraid of diverse threats brought by it. To help in its understanding, (Wierzbicki 2000) proposed a structural model of informational and knowledge civilization in the form of its three basic megatrends. These megatrends are the following:

1. The technological *megatrend of digital integration (*or *convergence).* Since all signals, measurements, data, etc. might be transformed to and transmitted in a uniform digital form, we observe today a long-term process of integrating various aspects of information technology. Telecommunication and computer networks are being integrated. Diverse aspects of the intelligence of networks, computers, decision support, and intelligence in our ambient habitat are becoming integrated. Diverse communication media – newspapers, books, radio, television – are becoming integrated and there are economic or political fights over who will control them. Formerly diversified information technologies – telecommunications, informatics, automatic control, electronic engineering – are becoming integrated, and so on. For many years to come this megatrend will define the directions of informational technology change.
2. The social *megatrend of changing professions (of de-materialization of work).* Together, information technology and the automation of heavy work will slowly result in a de-materialization of work. This, however, induces a rather rapid change in existing professions. In the industrial age it was sufficient to learn one profession that would last one's entire life, now we must re-learn our original or another profession several times over. Some old professions – such as type-setting – disappear, while others – such as industrial engineering - are essentially changed. The speed of this change is limited by socio-economic factors; technology would permit us to build fully automated, robotic factories even today, but what shall we do with the people who work in the existing factories?[10] Since not all people are equally adaptable, either

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[10] Thus, (Marcuse 1964) was essentially mistaken when painting technology as the reason for all the ills of modern society, of *technological, functionalist rationality.* Despite these accusations, technology developed that which Marcuse desired: the foundations of full *dematerialization of work.* Social and economic factors are responsible for the way technology is used, and contemporary sociology should concentrate on the challenges resulting from the new civilization era, instead of repeating old Marcuse'an accusations.

because of capability or because of limited circumstances, this megatrend results in both the *generation divide* and the *digital divide* between those who can speedily learn and profit from information technology and those who are excluded from this technological progress. The digital divide affects and concerns not only people in one country, also in diverse countries. The digital divide can threaten the existence of democratic society and the market economy as we know them now. Thus, it is essential to find ways to alleviate the effects of the digital divide and in particular to devise news professions, new occupations for people, as replacements for the old professions and occupations.

3. The intellectual *megatrend of mental challenges, of changing the way we perceive the world.* The perception of the world in industrial society was *mechanistic,* the world was perceived as a giant mechanism – a clock turning with the inevitability of celestial spheres. This resulted, on one hand, in the reduction principle described above, on the other, in the dominating belief in *inevitability*. For all specific differences, this belief equally motivated Kant (his *categorical imperative,* the transcendental moral principle *inevitably* follows logical reflection on the moral rights of fellow humans), Smith (the invisible hand of the market expresses *inevitability*) and Marx (with his *inevitability* of the laws of history). Such a way of perceiving the world still predominates - it can be noted especially in neo-liberal economic ideology, as exemplified, e.g., by the *End of History* (Fukuyama 1996) - and its change will be very difficult and will take time. However, it is very important to understand the change towards a *systemic, dynamic and chaotic* way of perceiving the world, which will be typical for the informational civilization.

1.6 The Need of a New Understanding of the World

During the last fifty years, systems research and systems science – including operational research, mathematical modeling,[11] and computerized techniques for mathematical model analysis and optimization, as well as so-called soft systemic thinking, etc. – contributed essentially to the change of perception of contemporary world, characteristic of the current informational revolution indicating the change of civilization eras. This has been supported by the developments of

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[11] In the interdisciplinary, applied sense, which differs essentially from the theory of mathematical models used in modern logic, even more than, e.g., applied gaming differs from game theory.

diverse systemic fields of technology – such as telecommunications, control engineering, computational science and intelligence, etc.

Modern advanced computations, operational research and mathematical computerized modeling create a virtual world, virtual laboratories for experimenting with models that express and organize knowledge about the real world. This fact is widely acknowledged today; however, it is less widely known that mathematical and computerized modeling was related to and strongly motivated many scientific and conceptual developments during the 20th Century, particularly in its second half. The beginnings of *linear programming* over 60 years ago motivated the first applications of digital computers; in addition, they promoted the development of entire fields such as operational research, logistics etc., and were also related to other fields such as cryptography. The computerized models and analysis of *dynamic system theory* were not only necessary for the automation of industrial processes, for automatic control of flying objects (aircraft, helicopters, rockets etc.), but they also motivated the entirely new deterministic theory of chaos. The *theory and computational practice of mathematical optimization* not only motivated the development of computational complexity theory, but also has shown the necessity for an entirely new way of understanding and modeling complex systems. Mathematical modeling became an essential part of *systems theory,* in particular in its *hard* dimension; as an antithesis, this motivated also the development first of *general systems theory,* later of *soft systems thinking,* or *critical systems approach,* with entirely different methods of problem solving stressing *synergy, holism, deliberation.* On the other hand, *hard* mathematical computerized modeling became also a basic tool for every *hard* science: physics, biology, chemistry, mechanical and civil engineering, telecommunications, etc. Usually, representatives of these sciences were originally convinced that only their way of mathematical modeling was important or even valid. Later they often found that they were rediscovering the methods developed earlier in some more general approaches to mathematical modeling or operational research and that this general discipline – or interdisciplinary field – provided them with a new understanding.

Mathematical and computerized modeling became also a necessary part of *computerized decision support,* including more *logical forms* of modeling typical for *artificial intelligence* and *knowledge engineering* as well as more *analytical forms* typical of engineering design, environmental applications etc. In the beginning of the 21st Century, together with the beginning of a new era of information and knowledge civilization, this contribution of mathematical modeling might be decisive for future applications. However, we shall focus here on two basic concepts that were developed because of mathematical modeling, although they have exceeded its domain and contributed essentially to the change in ways of perceiving the world that is typical for the beginnings of a new civilization era. These are the concepts of *chaos* and *complexity.*

For somebody who participated in the initial stages of the development of modern chaos theory, there is nothing astonishing in it. We needed to simulate random numbers in a digital computer, which is an essentially deterministic device; thus, we quite early discovered the principle of a quasi-random number generator that today would be called a chaotic generator of a strange attractor type. Although this is not stressed in the typical publications on the deterministic theory of chaos – see, e.g. (Gleick 1987) – the quasi-random number generators in digital computers were the first practical applications of the theory, actually preceding the development of the theory (when we learn to speak, we do not know that *we talk in prose*). The principle of such a generator exemplifies in fact the basic principles of a strange attractor: take a dynamic system with strong nonlinearity and include in it a sufficiently strong negative feedback to bring it close to instability. In the quasi-random generator, we use recourse, repetition instead of dynamics and feedback, and add a strong nonlinearity. The simplest example is: take a digital number, square it, cut out a quarter of its highest bits and a quarter of its lowest bits, and repeat the procedure. The resulting sequence of digital numbers is in fact periodic, but with a very long period and behaving meanwhile as if it were random.

We used industrial digital servomechanisms, thus we needed to understand the behavior of a digital servomechanism close to its instability, which is essentially another quasi-random generator. We needed to understand the limits of stability of industrial automatic control systems that are essentially nonlinear, thus we obtained behavior of a strange attractor type even when using analog computers. Therefore, for specialists in the mathematical modeling of nonlinear systems *there is nothing strange in strange attractors, in order emerging out of chaos, in the emergence of essentially new properties* because of the complexity of the system. Order can emerge out of deterministic chaos – say, in the form of snowflakes, see (Gleick 1987). Today, recourse with a strongly nonlinear operation is considered as a basic mechanism of order emerging from deterministic chaos, see, e.g., (Hu 1995), although strong nonlinear feedback was the original mechanism. On the other hand, order can also emerge from probabilistic chaos, as stressed by (Prigogine et al. 1984). The principle of order emerging from a probability distribution is mathematically rather simple: a strongly nonlinear transformation of a probability distribution can result in amplifying the probability of selected events, thus eventually in order.

This change of perception was postulated first by biological sciences, by the empirical observation of the phenomenon of *punctuated evolution.* However, it was technology or technical science, in particular informational science and telecommunications that have provided the pragmatic foundation of this change of perception, proving that in practice it is simply necessary if we want to master the complexity of modern technical systems. The best example is the multilayered ISO/OSI model of seven layers of a teleinformatic (computer) network. Developed just before 1980 and finalized in 1984, the model stresses that the functions of such complex network cannot be explained by the functions of its lowest, physical layer, by the way electronic switching elements work, repeat, and process signals. On each higher layer, new functions and properties of the network emerge. The functions of these layers, repeated here very briefly for illustration only, are as follows:

1. *Physical layer,* responsible for physical transmission of digital signals;
2. *Transmission layer,* responsible for transmission of sequences of bites in frames, discovery and correction of errors in this transmission;
3. *Network layer,* responsible for best routing of packets of frames between two end nodes of the network;
4. *Transport layer,* responsible for separation of the software from higher layers and from data transmission problems, and for providing error-free transmission with given quality indexes;
5. *Session layer,* responsible for synchronisation of data exchange;
6. *Presentation layer,* responsible for data presentation formats and interfaces with the final user,
7. *Application layer,* responsible for actual application software – transformation of data transmitted for the diverse purposes of its use.

The ISO/OSI model was used to unify the functions of various network protocols from TCP/IP family (IP, TCP, UDP etc.) that actually address the functions of various, though not necessarily separate, ISO/OSI layers. These protocols enabled the informational revolution that started not with the discovery of telephony, nor with the development of the digital computer, but with combining these two older discoveries into computer networks that brought digital information processing potentially to every home on our globe.

We should stress that the authors of the ISO/OSI model were not necessarily aware of changing the reduction paradigm to an emergence paradigm. They simply wanted to conquer the complexity of the modern telecommunication network and needed to assume the emergence of new properties of the system on higher layers because otherwise they would be lost in details. They might have been even unaware of the fact that the theory of hierarchical systems, including the theory of multilayered systems with many layers of qualitatively different functions, was developed some time earlier by control system theorists, see, e.g., (Findeisen at al. 1980).

However, in the example of ISO/OSI model we see also that:

Mathematical modeling and informational science prepared the way for a fundamental change in the way we perceive the world today.

The science of the industrial civilization era – particularly physics – perceived the world as a system that could be explained by the behavior of its elementary parts or particles.

This *reduction principle* – the reduction of the behavior of a complex system to the behavior of its parts – *is valid only if the level of complexity of the system is rather low.*

With the very complex systems of today, mathematical modeling, biological sciences but also technical and informational sciences adhere rather to the *emergence principle.*

The emergence principle stresses the emergence of new properties of a system with an increased level of complexity, *properties which are qualitatively different than the properties of its parts.*

Together with these new properties, new concepts are necessary, irreducible to concepts and properties on lower levels of complexity, thus in a sense transcendental. This is a very basic change of perspective with fundamental ontological and epistemological consequences.

We should add that the concept of complexity is used above only in its general, qualitative sense, while today's mathematical modeling and information sciences have developed a specific, quantitative-qualitative *theory of computational complexity.* This theory describes – qualitatively but in quantitative terms – how the computational effort needed for solving a given type of data processing or operational research problem depends on the dimension of the problem or amount of data processed. The main conclusion of this theory is that such dependence is highly nonlinear – very seldom linear, polynomial only for rather simple problems, exponential or combinatorial for most complicated problems. We shall use an approximate conclusion of this theory in a rational explanation of intuition, presented in the next chapter.

As we indicated above, the modern theory of chaos – see, e.g., (Gleick 1987) – helps us to understand the world by describing various ways of *order emerging out of chaos*, which in turn motivates the paradigm change from the *reduction principle* to the *emergence principle.* However, this theory also contributes another concept - that of the *butterfly effect: a* small change in the initial conditions of a complex dynamic system can result in essential changes in systems behavior.[12] Thus, the modern theory of chaos dispenses also with the belief in *inevitability*.

Informatics and computer science provided a competitive vision of the world – to perceive the world as a giant computer. This vision was promoted by *cognitive science* – see, e.g., (Gardner 1985) - that attempted to explain the functioning of human mind by an analogy to a giant computer, or even to its prototype, the Turing machine. Today, we can say that human mind is much more complicated (see next chapter), therefore, the entire world is also more complicated. The vision of the cognitive sciences and artificial intelligence was also clearly reductionist. Because of the paradigmatic change from the principle of reduction to the principle of emergence, the specialists in artificial intelligence express only the hope today that the increasing complexity of modern computers will somehow spontaneously result in the emergence of computer intelligence. Thus, the vision of the world as a giant computer loses its appeal.

On the other hand, there are several other aspects of the change in perceiving the world that can be described as a *systemic perspective.* Parts of this perspective depend on social and management systemic perspectives, *soft and critical systemic thinking,* see (Jackson 2000), (Midgley 2003); while this perspective provides important contributions, it is also often essentially reductionist and must be accordingly changed. However, the systemic perspective also includes non-reductionist contributions from mathematical modeling, in particular – so called *soft computing,* with *fuzzy set* (infinitely valued) logic and *rough set* (tertiary valued) logic. While fuzzy set theory is broadly known and applied, rough set theory, introduced by (Pawlak 1991), has only recently been found to also have many applications and is now being actively developed – see, (Słowiński 1995), Orłowska (1998). Thus, the principle of the excluded middle (*there is no third way)* is no longer universally valid in the world of an informational and knowledge civilization.

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[12] This effect, shown in a study of mathematical models of meteorology used for weather prediction (Lorenz 1963), was in fact the beginning of purposeful investigations of *deterministic chaos theory* (while actual applications of such chaotic effects, such as the *quasi-random number generator,* preceded the formation of the theory).

1.7 The Challenge to Epistemology

The new civilization age, the new understanding of the world, results in essentially new challenges to epistemology. Philosophers – e.g., (Searle 1992), (Motycka 1998) – sense this intuitively, perceive the necessity of abandoning reductionism and using the emergence principle instead, but these challenges are actually broader.

In the new civilization age, if knowledge becomes the decisive productive resource, it is simply necessary to understand in more detail how knowledge is created. Such *micro-theories of knowledge creation for today and tomorrow* are needed e.g. in order to construct software systems supporting this creation, using *computational intelligence* and the experiences in construction of computerized *decision support systems.*

It is also necessary to include technology creation in the new understanding, for many reasons. Without understanding how technology is created, we will fail to understand how to take full advantage of the opportunities and how to counteract the basic threats related to the new civilization age. It is not sufficient to say that modern advanced, technologically shaped society makes the man single-dimensional (Marcuse 1964); the Internet will impact our lives despite these warnings, and in order to make the best of this impact we should understand it. It is not sufficient to say, either, that science and technology are influenced by power, market and money and thus their truth is relative (Bloor 1976); without understanding why we need truth and objectivity in the new civilization era, we really give up their definition to market forces.

But there are additional reasons why a new understanding should be created. As we already observed, the philosophy of the 20th Century was fascinated with language. This started with logical empiricism – since logic is the science of the correct use of linguistic arguments – and dominated most of the diverse trends of philosophy of science. This domination of epistemology with linguistics is stressed, e.g. by (Czarnocka 2003). How much of it remains useful if, as we show in Chapter 2, most creative abilities are preverbal and language is but an imprecise code?

These challenges are great and will not be resolved by this book that attempts only to propose a preliminary synthesis of the new *micro-theories of knowledge creation*.

1.8 The Contents of this Book and Related Issues

This book, *Creative Space,* beside this introductory chapter consists of Part I: *Models of Creative Processes* that contains three chapters devoted to diverse representations of creative processes, thus related to epistemological and ontological issues: on *Rational Theory of Intuition* and its epistemological consequences, on the concept of *Creative Space,* and on further dimensions of *Creative Space.* Then Part II: *Issues of Knowledge Civilization Age* follows, containing two chapters: on a vision of new civilisation era and on necessary changes in the meaning of systems science. Part III: *Towards Knowledge and Technology Creation Support* includes a chapter on decision support versus creativity support and a final summarizing chapter.

We should warn the reader that there are many dichotomies, dialectic dyads stressed in this book: *Rational* versus *A-Rational, Objectivity* versus *(Inter-)Subjectivity, Occidental* versus *Oriental, Hard* versus *Soft,* etc., and the reader might feel that she (or he) obtains mixed signals about the value of them: one or the other part of the dyad might appear more valuable in one aspect, less valuable in another aspect.

We do not seek a comparison what is more valuable, we seek a synthesis and understanding. In particular, we try to abandon binary logic of such comparisons, to use at least trinary, *rough* logic (Pawlak 1991). In fact, the main concept of this book, the *Creative Space,* is based on such an extension from binary to trinary logic.

One additional comment should be stressed concerning the dichotomy East-West or Oriental-Occidental:

We oppose Kipling's opinion that *East is East and West is West and they shall never meet;* in times of globalization, and the informational and knowledge based revolution, such a meeting is not only inevitable, but also necessary.

We intend to write a follow-up to this book, *Creative Environments,* which will discuss in detail tools for knowledge and technology creation support: existing creative environments, the question what support is mainly needed for science and technology creation, issues such as virtual laboratories, support in brainstorming, support in roadmapping, support in gaming, distance learning and teaching, etc.

The authors would like to thank the many colleagues and students who have already contributed to this book and who cooperate with us on further

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