Chapter 1

Introduction

It is impossible to defeat an ignorant man by argument.
William McAdoo

… I had thought that the magic of the information age was that
it allowed us to know more,
but then I realized that the magic of the information age was that
it allowed us to know less.
David Brooks

We live in the world where information is everywhere. All knowledge is possible only because we receive, collect and produce information. People discovered existence of information and now talk of information is everywhere in our society. As Barwise and Seligman write (1997), in recent years, information became all the rage. The reason is that people are immersed in information, they cannot live without information and they are information systems themselves. The whole life is based on information processes as Loewenstein convincingly demonstrates in his book (1999). Information has become a key concept in sociology, political science, and the economics of the so-called information society. Thus, to better understand life, society, technology and many other things, we need to know what information is and how it behaves. Debons and Horne write (1997), if information science is to be a science of information, then some clear understanding of the object in question requires definition. That is why in the first section of this chapter, we show different approaches to defining and understanding information, demonstrating what conundrum exists in this area.

In the second section, we discuss the role of information in society. In the third section, we examine the role of information in nature. In the fourth section, technological aspects of information are considered. The last section of Introduction reveals the goals and structure of the whole book.

1.1. How Do We Know What Information Is?

Five paths to a single destination. What a waste.
Better a labyrinth that leads everywhere and nowhere.
Umberto Eco, *Foucalt's Pendulum*

Etymologically the term information is a noun formed from the verb "*to inform*", which was borrowed in the 15th century from the Latin word "*informare*", which means "*to give form to*", "*to shape*", or "*to form*".

As Capurro writes (1978; 1991), "key theories of Greek ontology and epistemology based on the concepts of *typos, idéa* and *morphé* were at the origin of the Latin term *informatio*. These connotations were maintained throughout the Middle Ages but disappeared as scholastic ontology was superseded by modern science."

During the Renaissance the word "*to inform*" was synonymous to the word "*to instruct.*" Later its meaning extended essentially and it became one of the most important technical and scientific terms. One of the most common ways to define information is to describe it as one or more statements or facts that are received by people and that have some form of worth to the recipient (Losee, 1997).

A detailed exposition for the etymological and historical background of the meaning of the term "information" is given by Capurro (1978). Here we are mostly interested in the scientific meaning of this term.

The problem with the word *information* is that the concept seems so intuitive and pervasive that people do not think a lot about it. However, Martin (1995) writes:

What is information? ... although the question may appear rhetorical, there is a sense in which the answer is that nobody really knows.

Thus, academics have long arguments about what constitutes information and many tried to answer the question "What is Information?"

The outstanding American mathematician and cybernetician Norbert Wiener (1894–1964) was one of the first who considered information beyond its day-to-day usage. He was one of the founders of cybernetics as a scientific discipline. The aim was to bring together similar research efforts in communication engineering, psychology, sociology, biology and medicine. From the point of view of these disciplines, it is above all the quantity of information which, apart from message, amount of interference (noise) and coding technique, is to be accounted for. According to Wiener the transmission of information is only possible as a transmission of alternatives, for if only a message about one possible state is to be transmitted it is most easily done by not transmitting any information at all. Therefore he calls for the development of a statistical theory of the amount of information, a quantity that has natural affinities to entropy in statistical mechanics. While the amount of information of a system is a measure of the degree of order, the entropy of a system is one of the measures of the degree of disorder. However, this did not solve the question of a concept of information proper. Throughout his life Wiener attached special importance to finding an answer to this question. To this purpose he made use of the results of a long-term collaboration with medical scientists.

His research led Wiener to make the famous statement (cf., for example, (Wiener, 1961)):

"Information is information, not matter or energy."

Although it is not a definition of information, this statement contained the message that the actual objects used for communication, i.e., for conveying information, are less important than information itself.

Wiener also described information in a different way. He writes (1954) that information is a name for the content of what is exchanged with the outer world as we adjust to it, and make our adjustment felt upon it.

Chaitin (1999) developed this idea. He writes:

"The conventional view is that matter is primary, and that information, if it exists, emerges from the matter. But what if information is primary and matter is the secondary phenomenon! After all, the same information can have many different material representations in biology, in physics, and in psychology: DNA, RNA; DVD's, videotapes; long-term memory, short-term memory, nerve impulses, hormones. The material representation is irrelevant, what counts is the information itself. The same software can run on many machines.

INFORMATION is a really revolutionary new kind of concept, and recognition of this fact is one of the milestones of this age".

Even before Wiener, electrical engineers instead of providing a definition of information and looking for its intrinsic features, focused on measuring information, using the term to describe data transmission. The goal was to maximize information transmitted or received, or minimize noise, or both. In 1928, Hartley published a paper, called *Transmission of Information*. There he used the word information, and made explicitly clear the idea that information in this context was a measurable quantity. The suggested measure reflected only that the receiver was able to distinguish that one sequence of symbols had been sent rather than any other — quite regardless of any associated meaning or other psychological or semantic aspect the symbols might represent.

This venue of research successfully continued and since the time of Wiener's pioneering works, information science emerged giving birth to many information theories and producing a quantity of definitions of information. The birth of information theory is placed officially in 1948, when the outstanding American engineer and mathematician Claude Elwood Shannon (1916–2001) published his first epoch-making paper.

In this work, Shannon further developed works of Ralph Vinton Lyon Hartley (1888–1970) and Harry Nyquist (1889–1976), who introduced fundamental ideas related to the transmission of information in the context of the telegraph as a communications system.

Shannon himself applied the word *information* only in a descriptive sense to the output of an information source, and he stays resolutely within the framework of telecommunications, using the title *communication theory*. His followers renamed the theory *information theory*, and now, as Hajek writes, it is too late to revert to the name given by Shannon. Moreover, Shannon's theory is a kind of information theory as communication is information exchange. As this theory is built on statistical considerations, it is called *statistical information theory*.

Although Shannon called what he created a theory of communication and wrote not about information itself, but about quantity of information, his research made possible to elaborate some definitions of information.

In the 1950s and 1960s, Shannon's concept of information invaded various disciplines. Apart from the natural sciences and economics, it was mainly in the humanities, in particular, in cognitive psychology, that specialized definitions of information were elaborated (cf. (Gibson, 1966; Neisser, 1967; Seiffert, 1968; Attneave, 1974; Collins, 2007)). In addition, increasing efforts were made to develop a unified definition integrating all aspects of the problem that had already been investigated in individual disciplines. Important efforts for the development of a definition were made in semiotics, cybernetics and philosophy (cf. (MacKay, 1956; Shreider, 1967; Nauta 1970; Titze, 1971)). However, apart from a variety of verbal definitions and vague hints for the development of new information theories, these efforts have yielded little and have certainly not led to a generally accepted definition.

For the majority of people, the most popular idea is that information is a message or communication. But a message is not information because the same message can contain a lot of information for one person and no information for another person.

The most utilized scientific definition of information (cf., for example, (Hartley, 1928) or (Ursul, 1971)) is:

Information is the eliminated uncertainty. (1.1.1)

Another version of this definition treats information as a more general essence and has the following form:

Information is the eliminated uncertainty or reflected variety. (1.1.2)

For example, Rauterberg (1995) assumes that for representation of information processes in learning systems that interact with their environment, the concept of variety is more relevant than the concept of uncertainty reflected by probabilities in the formulas of Hartley and Shannon.

However, in many cases, people speak about receiving or transmitting information when the variety is undefined and there is no uncertainty. In other cases, there is variety without information.

This is illustrated by the opinions of different authors. For example, an interesting idea is suggested in the book of Knapp (1978) where variety is defined in the orthogonal way to information. In non-technical language, this means that variety, as a phenomenon, is essentially distinct from information. This approach correlates with what writes Wilson (1993): "*In the real world … we frequently receive communications of facts, data, news, or whatever which leave us more confused than ever. Under the formal definition these communications contain no information…*"

Both definitions (1.1.1) and (1.1.2) are based on Shannon's information theory (Shannon, 1948). This theory represents statistical approach to information and is the most popular now. However, one of the followers of Shannon, the well-known French scientist Leon Brillouin (1889–1969) wrote that in this theory "the human aspect of information" is completely ignored. As a result, statistical approach has been very misleading in social sciences and humanities. So, it was not by chance that Claude Shannon called it a theory of communication but not of information. Besides, Shannon himself never defined information and wrote only about the quantity of information.

As a result, many authors tried to define information independently of Shannon. This resulted in information studies perplexity. A vivid picture of confusion about information is given in the book of Poster (1990). He begins with the statement that information "*has become a privileged term in our culture that evokes a certain feature of the new cultural conjuncture and must be treated with suspicion*." He writes about "*many forms of information: words, numbers, music, visual images*". Describing the scientific approach, he writes that theorists like to define information in a broad sense "*simply as organization of matter and energy*". Poster (1990) also assumes that information in the narrow sense is that part of a communication that is not "lost" in its transmission. The part that is "lost" is noise. However, there is a lot of examples when information is lost in transmission and sometimes only noise is left. For instance (cf. (Burton, 1997), one of the great mathematicians Evariste Galois (1811–1834) submitted his very important results to the French Academy of Sciences. Another outstanding mathematician Augustin-Lois Cauchy (1789–1857), a member of the Academy and professor, was appointed referee. Cauchy either forgot or lost the communication of Galois, as well as another one presented later.

In an encyclopedic dictionary of semiotics, information has been defined the following way (Moles, 1994):

"In modern semiotics the word information has two meanings. The first is the common language acceptance: a message containing novelty. In the second, technical sense, it is the measurement of the quantity of novelty conveyed by a message..."

According to Borgman (1999) information is a relation between humans and physical reality and consists of signs, which within a certain context, inform people about things in reality. In contrast to this, Parker (1974) defines information as the pattern of organization of matter and energy.

Nauta (1970) establishes a close relation between information and improbability, saying:

"Information is news: what is known already is no information. So, something is information to the extent that it is unknown, unexpected, surprising, or improbable."

Some researchers define knowledge in terms of information, while other researchers define information in terms of knowledge. For instance, Brookes (1980) suggests that "information is a small piece of knowledge" and Kogut and Zander (1992) conceive information as "knowledge which can be transmitted without loss of integrity." At the same time, Meadow and Yuan write (1997) that knowledge is the accumulation and integration of information.

If we take such an authoritative source of definitions as The American Heritage Dictionary (1996), we see the following definitions.

Information is: **1.** Knowledge derived from study, experience, or instruction. **2.** Knowledge of a specific event or situation; intelligence. **3.** A collection of facts or data: "statistical information." **4.** The act of informing or the condition of being informed; communication of knowledge: "Safety instructions are provided for the information of our passengers." **5.** (in Computer Science) A nonaccidental signal or character used as an input to a computer or communications system. **6.** A numerical measure of the uncertainty of an experimental outcome. **7.** (in Law) A formal accusation of a crime made by a public officer rather than by grand jury indictment.

Similar definitions of information are in the Roget's New Thesaurus: **1**. That which is known about a specific subject or situation: data, fact (used in plural), intelligence, knowledge, lore. **2**. That which is known; the sum of what has been perceived, discovered, or inferred: knowledge, lore, wisdom.

Information is also considered as data (both factual and numeric) that is organized and imbued with meaning or as intelligence resulting from the assembly, analysis, or summary of data into a meaningful form (McGee, 1993; Walker, 1993). According Curtis (1989), information is data processed for a purpose. According Senn (1990), information is data presented in a form that meaningful to the recipient. However, while some associate information with data, others associate it with knowledge.

As a result, the term *information* has been used interchangeably with many other words, such as content, data, meaning, interpretation, significance, intentionality, semantics, knowledge, etc. In the field of knowledge acquisition and management, information is contrasted to knowledge. Some researchers assume that if Plato took knowledge to be "justified true belief", then information is what is left of knowledge when one takes away belief, justification, and truth.

Buckland (1991) analyzes the concept of information and comes to the conclusion that the word *information* is and can be used in the same meaning as knowledge. According to Godin (2008), studies of information economy started in 1950s with the information-as-knowledge approach. However, later this was changed to the conception of information as commodity or economic activity (late 1970s and early 1980s) and then to the conception of information as technology. Information came to be defined very broadly. It included just about anything that was intangible (Godin, 2008). All this adds confusion into understanding information as a phenomenon.

Moreover, in the textbook (O'Brien, 1995) used at universities and colleges, it is written that terms *data* and *information* can be used interchangeably, but while *data are raw material resources*, *information are data that has been transformed into a meaningful and useful context*. In (Laudon, 1996), we find a similar notion of information, which is defined as *an organized collection of data that can be understood*.

Lerner (1999; 2004; 2007) writes that information measures uncertainty, is characterized by an equivalent reduction of uncertainty, and has different measures.

One more definition of information is presented in (Rochester, 1996). According to him, *information is an organized collection of facts and data*. Rochester develops this definition through building a hierarchy in which data are transformed into information into knowledge into wisdom. Thus, information appears as an intermediate level leading from data to knowledge.

Ignoring that an "*organized collection*" is not a sufficiently exact concept, it is possible to come to a conclusion that we have an appropriate definition of information. This definition and similar ones are used in a lot of monographs and textbooks on computer science. Disregarding slight differences, we may assume that this is the most popular definition of information. This gives an impression that we actually have a working concept.

Many will say, "If such a definition exists and people who are experts and information theory in computer science use it, then what's wrong with it? Why we need something else?"

To explain why this definition is actually incoherent, let us consider some examples where information is involved.

The first example is dealing with a text that contains a lot of highly organized data. However, this text is written in Chinese. An individual, who does not know Chinese, cannot understand this text. Consequently, it contains no information for this person because such a person cannot distinct this text from a senseless collection of hieroglyphs. Thus, we have a collection of organized data, but it contains information only for those who know Chinese. Thus, we come to a conclusion that information is something different from this collection of organized data.

It is possible to speculate that this collection of data is really information but it is accessible only by those who can understand the text. In our case, they are those who know Chinese.

Nevertheless, this is not the case. To explain this, we consider the second example. We have another text, which is a review paper in mathematics. Three people, a high level mathematician **A**, a mathematics major **B**, and a layman **C**, encounter this paper, which is in the field of expertise of **A**. After all three of them read or tried to read the paper, they come to the following conclusion. The paper contains very little information for **A** because he already knows what is written in it. The paper contains no information for **C** because he does not understand it. The paper contains a lot of information for **B** because he can understand it and knows very little about the material that is presented in it.

So, the paper contains different information for each of them. At the same time, data in the paper are not changing as well as their organization.

This vividly shows that data, even with a high organization, and information have an extremely distinct nature. Structuring and restructuring cannot eliminate these distinctions.

Although informatics, information science, and computer science are often in the spotlight, they do not provide necessary understanding of the situation and the word "information" is often used without careful consideration of the various meanings it has acquired.

For instance, *information science* is the study of the gathering, organizing, storing, retrieving, dissemination of information (Bates, 1999). In a more general interpretation, it is a study of all aspects of information: information processes, properties, functions, relations, systems, etc. For instance, Borko (1968) wrote:

"Information science is the discipline that investigates the properties and behavior of information, the forces governing the flow of information, and the means of processing information for optimum accessibility and usability. It is concerned with the body of knowledge related to the origination, collection, organization, storage, retrieval, interpretation, transmission, transformation, and utilization of information."

Giving an overview of the controversy over the concept of information, Qvortrup writes (1993):

"Thus, actually two conflicting metaphors are being used: The well-known metaphor of information as a quantity, like water in the water-pipe, is at work [see also conduit metaphor], but so is a second metaphor, that of information as a choice, a choice made by an information provider, and a forced choice made by an information receiver.

Information is the state of a system of interest (curiosity). Message is the information materialized."

Hu and Feng (2006) define *information*, carried by non-empty, well-formed, meaningful, and truthful data, as a set of states of affairs, which are part of the real world and independent of its receivers.

Bunge and Ardila (1987) distinguish between the following seven different ways in which the term *information* is used:

1. Information as meaning (semantic information).
2. Information as the structure of genetic material (genetic "information").
3. Information as a signal.
4. Information as a message carried by a pulse-coded signal.
5. Information as the quantity of information carried by a signal in a system.
6. Information as knowledge.
7. Information in a sense of communication of information (knowledge) by social behavior (e.g., speech) involving a signal.

Wersig (1997) separates six types of information understanding in information theory:

Structures of the world are information.

Knowledge developed from perception is information.

Message is information.

Meaning assigned to data is information.

Effect of a specific process, e.g., reducing uncertainty or change of knowledge, is information.

Process, commonly a process of transfer, is information.

One more example of the general confusion about information is that some, may be the majority of researchers, relate information only to society or, at least, to intelligent systems (cf., for example, (O'Brien, 1995) or (Laudon, 1996)), while others contradict information and communication, treating information as a category of solely physical systems (cf., for example, (Bougnoux, 1995)).

In addition to this, there were other problems with theoretical studies of information. For example, Shannon's information theory applies only in those contexts where its precise assumptions hold, i.e., never in reality. However, experts in information studies understood that this does not imply that an attempt to create a more general theory of information should not be pursued. On the contrary it should. The existing theories are actually too restrictive.

Many researchers consider information as an individual's brain construction (cf., for example, (Maturana and Varela, 1980; von Foerster, 1980, 1984; Flückiger, 1999)). According to Qvortrup (1993), treating information as a mental difference "doesn't necessarily imply that the difference in reality that triggered the mental difference called information is a mental construction."

Mackay (1969) suggests, "information is a *distinction* that makes a difference." A more metaphorical definition of Bateson (1972) describes *information* as "a difference that makes a difference." Clancey (1997) expanded Bateson's definition, proposing that *information* is the detection of a difference that is functionally important for an agent to adapt to a certain context. Muller (2007) assumes that "information is the facility of an object to distinguish itself." In the same venue, Markov, et al (2007) write that when a triad

(*source*, *evidence*, *recipient*)

exists, then the reflection of the first entity in the second one is called information. Thus, *information* is interpreted as a specific reflection.

At the same time, some researchers try to define information, using various abstract concepts. For instance, Crutchfield (1990) defines information of a source S as the equivalence class of all recordings of the symbol sequences from S. This is an interesting definition. However, it does not allow one to consider many kinds of information that is not represented by symbol sequences.

In algorithmic information theory (Kolmogorov, 1965; Chaitin, 1977), information is treated as tentatively *eliminated complexity*.

Many researchers do not discern information and a measure of information. For instance, in a well-written book of Abramson (1963), there is a section with the title "The definition of Information." However, it contains only one definition, which tells us how much information we get being told that some event occurred. Naturally, this does not explain what information is.

An interesting definition is suggested by Carl Friedrich Freiherr von Weizsäcker (1912–2007), who writes, "information is a quantitative measure of form (Gestalt)" (von Weizsäcker, 2006) and conceives information as a twofold category: (1) information is only that which is understood; (2) Information is only that which generates information (von Weizsäcker, 1974).

Losee (1997) uses the following definition of information:

Information is produced by all processes and it is the values of characteristics in the processes' output that are information.

Hobart and Schiffman (2000) suggest that the concept of information changes with time. They distinguish between classical, modern, and contemporary information ages, the meaning of information being unique to each age.

Information as a term is often closely related to such concepts as meaning, knowledge, instruction, communication, representation, and mental stimulus. For instance, information is treated as a message received and understood. In terms of data, information is defined as a collection of facts from which conclusions may be drawn. There are many other aspects of information that influence its definition. As a result, it is assumed that information is the knowledge acquired through study or experience or instruction. We see here information being a message, collection of facts and knowledge, and this is really confusing.

At the same time, challenging understanding information as a message, Stonier (1997) writes that "information is the raw material which, when information-processed, may yield a message."

In general, information has been considered as the following essences: as structures; processes (like becoming informed); changes in a knowledge system; some type of knowledge (for example, as personal beliefs or recorded knowledge); some type of data; an indication; intelligence; lore; wisdom; an advice; an accusation; signals; facts; acts; messages; as different things; as meaning; and as an effect like elimination of uncertainty (Brillouin, 1957; Ursul, 1971; Wersig and Neveling, 1976; Buckland, 1991; Wilson, 1993; etc.).

Ruben (1992) considers information on three levels or orders: the biological level, individual/psychological level, and interpersonal/social/cultural level. Consequently, he distinguishes three rather distinct concepts of information. The first order of information, which exists on the biological level and called *Information*$_e$, is environmental data, stimuli, messages, or cues — artifacts and representations — which exist in the external environment. The second order of information, which exists on the individual/psychological level and called *Information*$_i$, is that which has been transformed and configured for use by a living system. It includes cognitive maps, cognitive schemes, semantic networks, personal constructs, images, and rules, i.e., internalized and individualized appropriations and representations. The third order of information, which exists on the social and cultural level and called *Information*$_s$, comprises the shared information/knowledge base of societies and other social system, i.e., socially constructed, negotiated, validated, sanctioned and/or privileged appropriations, representations, and artifacts.

While information has been defined in innumerable ways, there have been a lot of discussions and different approaches have been suggested trying to answer the question what information is. According to (Flückiger, 1995), in modern information theory a distinction is made between structural-attributive and functional-cybernetic types of theories. While representatives of the former approach conceive information as structure, like knowledge or data, variety, order, and so on; members of the latter understand information as functionality, functional meaning or as a property of organized systems.

Krippendorff (1994) explores different information and communication metaphors, such as information as a message transmission, the container metaphor, the metaphor of sharing common views, the argument metaphor, the canal metaphor, and the control metaphor. These metaphors, originating within different cultural environments, reflect important traits of information and information processes. However, any metaphor can be misleading and it is necessary to use it creatively, that is, to see its limits and to learn how to apply it accurately in different theoretical and practical situations.

Braman (1989) provides an important discussion of approaches to defining information for policy makers. Four major views are identified: (1) information as a resource, (2) information as a commodity, (3) information as a perception of patterns, and (4) information as a constitutive force in society. The relative benefits and problems with each of these four conceptions are discussed. The article points out that the selection of one definition or another has important consequences, and also that the tendency to neglect this problem results in conflicts rather than cooperation. Defining information is thus also a political decision.

Consequently, it is not surprising that intelligent people come to a conclusion that the main problem is that people and even experts in the field do not really know what information is (Bosma, 1985). Information is a term with too many meanings depending on the context. The costs of searching in the wrong places have been high because the superficial considering of the nature of information have left researchers in information science without a proper theoretical foundation, which is a very serious situation for an academic field.

In one of his lectures the well-known American philosopher Searle stressed that "*the notion of information is extremely misleading*." Another well-known American philosopher Hintikka writes (1984), the concept of information is multiply ambiguous. At the same time, the famous French mathematician Rene Thom (1975) calls the word "*information*" a "*semantic chameleon*," that is something that changes itself easily to correspond to the environment. Various scientific and laymen imaginations about information stand often without the least explicit relationship to each other. Thus, we see that "too many" definitions may be as bad as "too few" ones. This has been noticed by researchers. For instance, Macgregor (2005) writes about conundrums for the informatics community caused by problems of defining information and finding the nature of information.

As Meadow assumes (1995), one of the problems all of researchers who study and try to measure the impact of information have is the multiple definitions of the very word *information*.

Van Rijsbergen and Laimas write (1996):

"*Information is and always has been an elusive concept; nevertheless many philosophers, mathematicians, logicians, and computer scientists have felt that it is fundamental. Many attempts have been made to come up with some sensible and intuitively acceptable definition of information; up to now, none of these succeded*."

Existing confusion with the concept of information is vividly rendered by Barwise and Seligman, who explain (1997):

"*There are no completely safe ways of talking about information. The metaphor of information flowing is often misleading when applied to specific items of information, even as the general picture is usefully evocative of movement in space and time. The metaphor of information content is even worse, suggesting as it does that the information is somehow intrinsically contained in one source and so is equally informative to everyone and in every context*."

One more problem is that trying to tell what information is a necessary clear distinction is not made between a definition and an attribute or feature of this concept. Normally, describing or naming one or two attributes is not considered a definition. However, there are authors who stress even a single feature of information to the point that it appears to be a definition.

Scarrott (1989) attracts attention to a dictionary definition of *information* as that which informs. This definition identifies *information* using a very vague term *to inform*, which, in turn, depends on the definition of information itself.

As a result of all inconsistencies related to the term *information*, many researchers prefer not to use the word *information*. As Crutchfield remarks (1990), "information generally is left undefined in information theory." Many experts believe that the attempt at information definition could present an act of futility (Debons and Horne, 1997).

Spang-Hanssen (2001, online) argues (cf. (Capuro and Hjorland, 2003)):

"In fact, we are not obliged to accept the word *information* as a professional term at all. It might be that this word is most useful when left without any formal definition, like e.g., the word *discussion*, or the word *difficulty*, or the word *literature*."

The term *information* is used in so many different contexts that a single precise definition encompassing all of its aspects can in principle not be formulated, argues Belkin (1978), indirectly quoting (Goffman, 1970).

An extreme point of view is to completely exclude the term information from the scientific lexicon and to abandon the term from the dictionary (Fairthorn, 1973). In the same way, in his paper "Information studies without information", Furner writes (2004) that it is easy to see that philosophers of language have modeled the phenomena fundamental to human communication in ways that do not require us to commit to a separate concept of "information." Thus, he concludes, such a concept as *information* is unnecessary for information studies. Once the concepts of interest in this area have been labeled with conventional names such as "data", "meaning", "communication", "relevance", etc., there is nothing left (so Furner argues) to which to apply the term "information."

While it is possible to partially agree with Furner in the first part of his claim. Namely, it is true that in many cases researchers use the word *information* when it is necessary to use some other word. In some cases, it may be the word *data*. In other cases, it may be the word *knowledge* or *message* and so on.

All this demonstrates that the existing variety of definitions lacks a system approach to the phenomenon, and for a long time there has been a need to elaborate a concept that reflects the main properties of information. This concept has to be the base for a new theory of information, giving an efficient tool for information processing and management. Mattessich (1993) assumes that the concept of information requires a conceptualizing process no less torturous than the one that purified the notion of energy during the last 200 years.

Meadow and Yuan (1997) argue:

"*How is it possible to formulate a scientific theory of information? The first requirement is to start from a precise definition.*"

In a similar way, many researchers insist that it is necessary to have a definition of information. For instance, Braman (1989) stresses how important it is for information policy to define information adequately. Mingers (1996) argues, if information theory is to become a properly founded discipline, then it must make an attempt to clarify its fundamental concepts, starting with the concept of information.

The opening paragraph in the preface of the monograph of Barwise and Seligman (1997) states that there is no accepted science of information. Lenski (2004) adds to this that as a broadly accepted *science* of information is not envisaged by now, a commonly acknowledged *theory* of information processing is out of sight as well.

However, knowing about information is not only a theoretical necessity but is a practical demand. Considering the United States of America in the information age, Giuliano (1983) states that the "*informatization process is very poorly understood. One of the reasons for this is that information work is very often seen as overhead; as something that is necessary but not contributory*."

In a similar way, Scarrott writes (1989):

"*During the last few years many of the more perceptive workers in the information systems field have become uneasily aware that, despite the triumphant progress of information technology, there is still no generally agreed answers to the simple questions — What is information? Has information natural properties? What are they? — so that their subject lacks trustworthy foundations*."

Capuro and Hjorland (2003) also stress, "for a science like information science (IS) it is of course important how fundamental terms are defined." In addition, they assume that even "discussions about the concept of information in other disciplines are very important for IS because many theories and approaches in IS have their origins elsewhere."

This supports opinion of those researchers who argued that multifarious usage of the term *information* precludes the possibility of developing a rigorous and coherent definition (cf., for example, (Mingers, 1996)). Nevertheless, if information studies are to become a properly founded discipline, then it is necessary to clarify its most fundamental concept *information* (cf., for example, (Cornelius, 2002)).

The reason is the perplexing situation with information science. Schrader (1983) who analyzed this situation came to the following conclusion.

"*The literature of information science is characterized by conceptual chaos. This conceptual chaos issues from a variety of problems in the definitional literature of information science: uncritical citing of previous definitions; conflating of study and practice; obsessive claims to scientific status; a narrow view of technology; disregard for literature without the science or technology label; inappropriate analogies; circular definition; and, the multiplicity of vague, contradictory, and sometimes bizarre notions of the nature of the term 'information'*."

In addition, in spite of a multitude of papers and books concerning information and a lot of studies in this area, many important properties of information are unknown. As Wilson writes (1993), "'*Information*' *is such a widely used word, such a commonsensical word, that it may seem surprising that it has given 'information scientists' so much trouble over the years*." This is one of the reasons why no adequate concept (as well as understanding) of information phenomenon has been produced by information theory till the last decade of the 20th century.

Machlup and Mansfield (1983) presented key views on the interdisciplinary controversy over the concept of information in computer science, artificial intelligence, library and information science, linguistics, psychology, and physics, as well as in the social sciences.

Thus, it is not a surprise that, as Dretske (1981), Lewis (1991) and Mingers (1996) point out, few books concerning information systems actually define the concept of information clearly.

Kellogg (http://www.patrickkellogg.com/school/papers/) tells that at a talk he attended, the invited speaker started out by saying that the concept of information was universal, and that nobody could argue about its definition. "Aliens from another planet", the speaker claimed, "would agree with us instantly about what information is and what it isn't" and then for the rest of his talk, the speaker avoided giving a clear definition.

According to Sholle (1999), the information society is being sold to the average citizen as providing access to knowledge, meaningful dialogue and information essential to everyday decision-making. At the same time, even within the marketing of the information society and its benefits, *the actual nature of the information and knowledge produced and distributed by information technology remains abstract and actually undefined*. Instead, government and corporate pronouncements focus on the sheer power of the network, on the technological magic of information machines, on the overall capacity of the system, and on the abstract phenomenon of "being digital".

Many researchers assume that this diversity of information uses forms an insurmountable obstacle to creation of a unified comprehensible information theory (cf., for example, (Capurro, et al, 1999; Melik-Gaikazyan, 1997)). Capuro (Capuro, Fleissner, and Hofkirchner, 1999) even gives an informal proof of the, so-called, Capuro trilemma that implies impossibility of a unified theory of information. According to his understanding, information may mean the same at all levels (univocity), or something similar (analogy), or something different (equivocity). In the first case, we lose all qualitative differences, as for instance, when we say that e-mail and cell reproduction are the same kind of information process. Not only the "stuff" and the structure but also the processes in cells and computer devices are rather different from each other. If we say the concept of information is being used analogically, then we have to state what the "original" meaning is. If it is the concept of information at the human level, then we are confronted with anthropomorphisms if we use it at a non-human level. We would say that "in some way" atoms "talk" to each other, etc. Finally, there is equivocity, which means that information cannot be a unifying concept any more, i.e., it cannot be the basis for the new paradigm…

It has been argued, for example, by Goffman (1970) and Gilligan (1994), that the term *information* has been used in so many different and sometimes incommensurable ways, forms and contexts that it is not even worthwhile to elaborate a single conceptualization achieving general agreement.

Shannon (1993) also was very cautious writing: "It is hardly to be expected that a single concept of information would satisfactorily account for the numerous possible applications of this general field."

Flückiger (1995) came to the conclusion that those working in areas directly related to information had apparently accepted that the problem with the definition would remain unsolved and considered Shannon's concept of information as the most appropriate.

Agre (1995) argues that the notion of information is itself a myth, mobilized to support certain institutions, such as libraries. Bowker (1994) discusses other mythologies that support the notion of information.

It may be caused by poor understanding the complex term *information* by many people, that other ways of using the word *information*, for example, as bits of information (cf., Chapter 3), have had a much stronger appeal. However, while the concept of a *bit* may allow one to measure the capacity of a floppy disc or a hard-disk, it is useless in relation to tasks such as indexing, collection management, document retrieval, bibliometrics and so on. For such purposes, the meaning of the signs must be involved, making a kind of semantic information theory a much better theoretical frame of reference compared to statistical information theory. An objective and universalistic theory of information has a much stronger appeal than theoretical views that make information, meaning and decisions context-dependent. However, the costs of searching in the wrong places have been high because the superficial considering of the nature of information leaves society without a proper theoretical foundation, which is a very serious situation for academic fields.

It is possible to compare the development of information sciences with the history of geometry. At first, different geometrical objects (lines, angles, circles, triangles etc.) have been investigated. When an adequate knowledge base of geometrical objects properties was created, a new step was taken by introducing the axiomatic theory, which is now called the Euclidean geometry. In a similar way, knowledge obtained in various directions of information theory (statistical (Shannon, 1948; Shannon and Weaver, 1949; Fisher, 1922; 1925), semantic (Bar-Hillel and Carnap, 1958), algorithmic (Solomonoff, 1964; Kolmogorov, 1965; Chaitin, 1977), qualitative (Mazur, 1984), economic (Marschak, 1971; 1980; 1980a), etc.) made it possible to make a new step — to elaborate a parametric theory called the general theory of information (GTI). As it is demonstrated in this book, all other known directions of information theory may be treated inside the general theory of information as its particular cases

The base of the general theory of information is a system of principles. There are two groups of such principles: ontological and axiological. Some of other approaches in information theory are also based on principles. For instance, Dretske (1981) considers the Xerox Principle and some others. Barwise and Seligman (1997) consider several principles of information flow.

It is necessary to remark that the general theory of information does not completely eliminate common understanding of the word information. This theory allows one to preserve common usage in a modified and refined form. For instance, when people say and write that *information is knowledge of a specific event or situation* (The American Heritage Dictionary, 1996), the general theory of information suggests that it is more adequate to say and write that *information gives knowledge of a specific event or situation*. When people say and write that *information is a collection of facts or data* (The American Heritage Dictionary, 1996), the general theory of information suggests that it is more adequate to say and write that *a collection of facts or data contains information*.

Derr (1985) give an analysis of the notion of information as used in ordinary language. This analysis shows that the general theory of information allows one to refine this usage, making it more consistent.

Thus, we can see that it is possible to divide all popular definitions of information into several classes. In one perspective, information is an objective essence, e.g., some kind of enhanced data. An alternative view emphasizes the subjective nature of information when the same carrier provides different information to different systems. Another dimension of information also has two categories: information as a thing and information as a property. According to Buckland (1991), the term *information* is used in different ways, including "information-as-knowledge", "information-as-thing" (e.g., data, signals, documents, etc.), and "information-as-process" (e.g., becoming or being informed).

The situation with information reminds us the famous ancient story of the blind men and an elephant. It had been used by many for different purposes, originating from India, having different versions, and being attributed to the Hindus, Buddhists or Jainists. Here we present a combined version of this tale, in which ten blind men are participating.

Once upon a time there was a certain raja, who called to his servant and said, "Go and gather together near my palace ten men who were born blind... and show them an elephant." The servant did as the raja commanded him. When the blind men came, the raja said to them, "Here is an elephant. Examine it and tell me what sort of thing the elephant is."

The first blind man who was tall found the head and said, "An elephant is like a big pot."

The second blind man who was small observed (by touching) the foot and declared, "An elephant is like a pillar".

The third blind man who was always methodical heard and felt the air as it was pushed by the elephant's flapping ear. Then he grasped the ear itself and felt its thin roughness. He laughed with delight, saying "This elephant is like a fan."

The fourth blind man who was very humble observed (by touching) the tail and said, "An elephant is like a frayed bit of rope."

The fifth blind man who was daring walked into the elephant's tusk. He felt the hard, smooth ivory surface of the tusk and its pointed tip. "The elephant is hard and sharp like a spear," he concluded.

The sixth blind man who was small observed (by touching) the tuft of the tail and said, "An elephant is like a brush."

The seventh blind man who felt the trunk insisted the elephant was like a tree branch.

The eighth blind man who was always in a hurry bumped into the back and reckoned the elephant was like a mortar.

The ninth blind man was very tall. In his haste, he ran straight into the side of the elephant. He spread out his arms and felt the animal's broad, smooth side and said, "This is an animal is like a wall."

Then these nine blind men began to quarrel, shouting, "Yes it is!", "No, it is not!", "An elephant is not that!", "'Yes, it's like that!" and so on.

The tenth blind man was very smart. He waited until all others made observations and told what they had found. He listened for a while how they quarreled. Then he walked all around the elephant, touching every part of it, smelling it, listening to all of its sounds. Finally he said, "I do not know what an elephant is like. That is why I am going to write an Elephant Veda, proving that it is impossible to tell what sort of thing the elephant is."

One more paradox related to information studies is that what is called information theory is not regarded as part of information science (IS) by many researchers (Hjørland, 1998). Concentrating on properties of information systems, such as information retrieval systems and libraries, behavior of their users, and functioning information carriers and representations, such as descriptors, citations, documents, titles and so on, information science paid much less attention to information itself.

Nevertheless, those information theories that have been created were found very useful in many practical and theoretical areas — from technology of communication and computation to physics, chemistry, and biology. That is why we are going to consider the essence of those information theories and explain their usefulness. However, before starting such an exposition, we informally consider the role and place of information in nature, society, and technology.

1.2. Information in Society

He that has knowledge spares his words:
and a man of understanding is of an excellent spirit.
Bible, Proverbs (Ch. XVII, v. 27)

Many books and numerous papers are written on social problems related to information. Here we give a general perspective on the situation and consider some of existing problems in this area.

Information plays more and more important and explicit role in society. Researchers understand information as a basic relationship between humans and reality (cf., for example, (Borgmann, 1999)). Information and information technology acquire a central place in public discourses. For instance, a search for the word *information* gave 3,710,000,000 results in 0.33 seconds with Google, gave 15,300,000,000 results in 0.23 seconds with Yahoo, and gave 1,220,000,000 results with AOL.

The outstanding role of information in culture is well understandable. Cultures exist and grow only due to information storage and transfer. Communication, i.e., information exchange, is one of the cornerstones of culture. Many cultural phenomena are studied from the communication perspective. The communicative approach to cultural studies assumes existence of a specific communication structure as a system of information interactions (Parahonsky, 1988). For instance, communication relations in art are based on the following communication triad (Kagan, 1984):

$$\textbf{Artist} \longrightarrow \textbf{Recipient(s)} \qquad (1.2.1)$$

This shows communication of the artist with her or his audience.

It is possible to extend this communication triad to the following composition of two triads:

$$\textbf{Artist} \longrightarrow \textbf{Piece of art} \longrightarrow \textbf{Recipient(s)} \qquad (1.2.2)$$

The first triad reflects creation of the piece of art (painting sculpture, movie, etc.) by the artist, while the second triad shows how this piece of art influences the audience. This influence has an exclusively informational nature.

In the case, when an artist is a composer, playwright or screenwriter, the cultural communication triad (1.2.1) has to be extended to the following triad:

$$\textbf{Artist} \longrightarrow \textbf{Performer(s)} \longrightarrow \textbf{Recipient(s)} \qquad (1.2.3)$$

In the process of creation, an artist usually communicates with herself or himself. This gives us the cultural self-communication triad:

$$\textbf{Artist A} \longrightarrow \textbf{Artist A} \qquad (1.2.4)$$

Such exceptionally important processes as teaching and learning have information nature (Burgin, 2001a; Parker, 2001). Teaching always goes in communication and thus, it is based on information exchange (Burgin and Neishtadt, 1993). Learning also includes explicit and/or implicit communication, such as communication with nature in an experiment.

Actually, the whole society exists only because people and organizations are communicating. Without communication society is impossible. Even animals, birds and insects (such as bees and ants) are communicating with one another when they form a social group.

In addition, the role of information in economy has been growing very fast. Information is the key to management, research and development. In modern business, information is of primary interest. As Scarrott writes (1989), the most basic function of information is to control action in an organized system and thereby operate the organization. Thus, organizations exist only due to information exchange. Business processes, such as planning, product development, management, production, purchasing, advertising, promoting, marketing, selling, not only drive all businesses, but also generate valuable information.

There are different images of organizations: as machines, organisms, political systems, cultures, and learners (Morgan, 1998; Senge, 1990; Kirk, 1999). The *machine image* suggests that information is one of the resources that keep the wheels ticking over. The *organism image* implies that information from internal and external sources is required to keep the organization in the state of equilibrium. The *learner image* portrays an organization as a system based on obtaining information.

Thus, it is possible to consider any organization as an information processing engine. Information on many issues is represented by data in various databases: personnel databases, production databases, billing and collection databases, sales management databases, customer databases, supply chain databases, accounting databases, financial databases, and so on.

This explicates and stresses importance of information management. The work of managers in organizations, such as companies and enterprises, is very information-intensive, and the result of their work depends on information management to a great extent. As a result, information management contributes (in a positive or negative way) to the achievements of organizations, is used in a political, social and cultural contexts, has ethical dimensions and is value-laden (Kirk, 1999).

An important element in information management is information politics, which reflects rules and assumptions made about how people and organizations generate, preserve and use information. Davenport, et al, (1996) distinguish four types of information politics:

Technocratic utopianism is a heavily technological approach to information management stressing categorization and modeling of organization's full information assets.

Anarchy is characterized by the absence of any overall information management policy leaving individuals to obtain and manage their own information.

Feudalism is the management of information by individual business units groups, which define their own information needs and report only limited information to the overall corporation.

Federalism is an approach to information management based on consensus and negotiation on the organization's key information elements and reporting structures.

As Giachetti (1999) writes, global competition, shorter lead times and customer demands for increasing product variety have collectively forced manufacturing enterprises to develop rapidly, more closely collaborate with customers and suppliers, and more often introduce new products to obtain a quick return on their investment.

Information technology is regarded as means to solve basic problems in new product development, manufacture, and delivery.

The information economy is one of the key concepts to explain structural changes in the modern economy (Godin, 2008). Economical concern with information goes back to 1949. The Organization for European Economic Co-Operation (OEEC) organized a working party on scientific and technical information. The goal was to measure information activity as a tool to get science policy considerations into the organization. In these studies, information was treated as knowledge and limited to scientific and technological information. In turn, measurements and the corresponding statistics were limited to documentation in these areas.

In 1961, the Organization for Economic Cooperation and Development (OECD) was created. It continued research on information in society with the emphasis on the information economy. In this process, such fields as informatics aimed at a study of scientific information and science of science with its subfields: scientometrics, methodology of science, economy of science, politics in science and some others, emerged. The perspective on scientific and technical information was threefold: (1) information flow grows so fast that it can be called "information explosion"; (2) new technologies can tame this explosion; (3) this needs a common approach and united efforts of different countries (cf. (Godin, 2008)).

In 1969, the Information Policy Group of OECD suggested a methodological manual. It identified five specific classes of scientific and technical information activities (cf. (Godin, 2008)): (1) recording; (2) editing, revising, translating, etc. (3) distribution (including conferences); (4) collection, storage, processing; and (5) acquisition.

It is interesting to compare these information activities with information operations studied in the general theory of information

(Burgin, 1997b). There are three main classes of information operations with respect to a system *R*:

- *Informing* is an operation when (a portion of) information acts on *R*.
- *Information processing* is an operation when *R* acts on (a portion of) information.
- *Information utilization* is an operation when the system *R* acts on another system *Q* by means of information.

In turn, informing is also divided into three classes:

- *Information reception* is an operation when *R* gets information that comes from some source.
- *Information acquisition* is an operation when *R* performs work to get existing information.
- *Information production* is an operation when *R* produces new information.

Processing is divided into three classes:

- *Information transformation* is an operation when changes of information or its representation take place.
- *Information transition*, or as Bækgard (2006) calls it, *information movement*, is an operation when information is not changing but the place where the information carrier is changes.
- *Information storage* is an operation when information is not changing but time for the information carrier changes.

In turn, information transformation is also divided into three classes:

Information reconstruction is an operation when the initial information and/or its initial representation change.

Information construction is an operation when the initial information or/and its initial representation is not changing but new information and/or representation are created.

Information biconstruction is an operation when the initial information and/or its initial representation change and new information and/or representation are created.

In these terms, all information operations from the methodological manual — recording; editing, revising, and translating — are different kinds of information processing.

However, the methodological manual and the corresponding list of indicators suggested by the Information Policy Group of OECD were never used to measure scientific and technical information and related activities. Two factors explained this failure: the absence of the general conceptual framework and the fuzziness of the concept of information itself (Godin, 2008). This transparently shows how the lack of a good theory disables practical endeavors.

As importance of information was growing, researchers in the field started to consider information as a commodity in economic activity. In 1977, Porat and Rubin published a nine-volume study titled *The Information Economy*. The main assumption was that the USA and other developed countries have evolved from an economy based primarily in manufacturing and industry to one based primarily in knowledge, communication, and information. The goal was to get a total value of information in economy. Separating primary and secondary information sectors, the authors found that these sectors amounted to 46% of the US GNP and 53% of labor income in the USA. Now these numbers have become even larger.

As a result, deficiencies with information quality impose significant costs on individual companies, organizations, and the whole economy, resulting in the estimated costs only to the US economy at $600 billion per year (cf., (Hill, 2004)).

Although information still remains an economic commodity and its importance grows, the third period in information economy is characterized by the main emphasis on information technology, which occupies dominating positions in society.

That is why our time is often called *information age* (cf., for example, (Bell, 1973, 1980; Mason, 1986; Crawford and Bray-Crawford, 1995; Stephanidis, 2000)), while the modern society is called the *information society* (cf., for example, (Webster, 2002)). It is often used in conjunction with the term post-industrial society as it is usually related to a period after the industrial age. Braman (1989) treats information as a constitutive force in society. Information flow controls culture, education, technology, politics, and economy of the information society. Information is applied to a social structure of any degree of articulation and complexity. Its flow and use have an enormous power in constructing social reality.

It is impossible today to avoid constant reference to the *information age*. The phrase is so imbedded in our collective psyche that it can be used in any argument. We are "overwhelmed by the information age", or "our country needs to meet the challenges of the information age", the "information age" is good or the "information age" is causing information flood, knowledge pestilence and dire societal change.

According to Bougnoux (1993, 1995) the concepts of information and communication are inversely related. Communication is concerned with forecasting and redundancy, while information deals with the new and the unforeseen. There is no pure information or "information-in-itself" (that is, information is always related to some kind of redundancy or "noise"). To inform (others or oneself) means to select and to evaluate. This is particularly relevant in the field of journalism and mass media, but, of course, also in information science.

Information is playing an increasing role in our industrialized society. A technical overview of the flourishing electronics industry stated in 1987:

"*On almost every technology front, the driving force behind new developments is the ever-rising demand for information. Huge amounts of data and information, larger than anyone ever dreamed of a generation ago, have to move faster and faster through processors and networks, then end up having to be stored*" {Electronics, 1987, p.83}.

Four years later the *industrial age* had already given way to the *information age*. "In 1991 companies for the first time spent more on computing and communications gear — the capital goods of the new era — than on industrial, mining, farm, and construction machines. Infotech is now as vital, and often as intangible, as the air we breathe, which is filled with radio waves. In an automobile you notice the $675 worth of steel around you, but not the $782 worth of microelectronics" (Furth**,** 1994).

Information has become a highly valued economic category, on par with capital and skilled labor. The collection, structuring and processing of information consequently constitute one of the focal points of business. According to Poster (1990), the mode of information must now replace the mode of production as the key concept in a critical analysis of social formation. The three superseding historic modes are:

(1) spoken mode;
(2) printed mode;
(3) electronic mode.

A similar theoretical position was independently developed by Goguen (1997), who writes:

"*An item of information is an interpretation of a configuration of signs for which members of some social group are accountable. That information is tied to a particular, concrete situation and a particular social group has some important consequences* …"

Borgmann (1999) distinguishes three types of information in society: natural information, cultural information, and technological information.

Natural information is information about reality and is conveyed by natural signs, such as a tree, river, smoke, the Moon, etc.

Cultural information is information for reality and is conveyed by conventional signs, such as a digit, letter, etc.

Technological information is information as reality. It does not give an access to reality as two other types of information. Technological information replaces reality.

Economists discuss how to build economics of information and develop theories of information economy (Arrow, Marschak and Harris, 1951; Good, 1952; McCarthy, 1956; Marschak, 1954; 1959; 1964; 1971; 1972; 1974; 1976; 1980; 1980a; Stigler, 1961; Yasin, 1970; MacQueen and Marschak, 1975; Arrow, 1979; 1984; 1984a; Hirshliefer and Rilley, 1979; McCall, 1982; Phlips, 1988; Laffont, 1989; Babcock, 1990; Bernknopf, et al, 1997; Macauley, 1997; Teisberg and Weiher, 2000; Cockshott and Michaelson, 2005).

The accelerating development of the information technology has an ongoing impact on individuals and society as a whole (Brooks, 2007; Carr, 2008).

With the advent of the Internet and development of powerful search engines, people got an unexpected access to information. For many, the Internet is becoming a universal medium, the conduit for most of the information that flows through people's eyes and ears and into their mind (Carr, 2008). This new kind of information flow brought forth a new type of data called *stream data* (cf., for example, (Burgin and Eggert, 2004)). A collection of messages is an example of a stream data.

As McLuhan (1964) pointed, media are not just passive channels of information. They supply the stuff of thought, but they also shape the process of thought. This is especially true for the Internet: working with it disables capacity for concentration and contemplation. As a result, the mind expects to take in information the way the Internet distributes it: in a swiftly moving stream of particles. People loose the ability to read and absorb a longish article on the web or in print. Even a blog post or an e-mail of more than three or four paragraphs is too much to absorb. Thus, people skim them (Carr, 2008).

New information technologies always changed people behavior, abilities and the way of thinking. Long ago Plato bemoaned the development of writing. He feared that, as people came to rely on the written word as a substitute for the knowledge inside their heads, they would cease to exercise their memory and become forgetful. They would be filled with the conceit of wisdom instead of real wisdom. As Carr writes (2008), Socrates was not wrong — the new technology did often have the effects he feared — but he was shortsighted. He couldn't foresee the many ways that writing and reading would serve to spread information, spur fresh ideas, and expand human knowledge (if not wisdom).

The arrival of the printing press, in the 15th century, set off another round of worries. Italian humanists expressed a concern that the easy availability of books would lead to intellectual laziness, making men "less studious" and weakening their minds. Others argued that cheaply printed books and broadsheets would undermine religious authority, demean the work of scholars and scribes, and spread sedition and debauchery. As New York University professor Clay Shirky notes (cf., (Carr, 2008)), "Most of the arguments made against the printing press were correct, even prescient." However, those critics were unable to imagine the diversity of blessings that the printed word would deliver. Now similar concerns are related to computers and the Internet, which have both positive and negative impact on society and individuals.

1.3. Information in Nature

Absence of evidence is not an evidence of absence
Christian De Duve

There is some controversy with respect to the role of information in nature. The spectrum of opinions ranges from complete rejection of existence information beyond society (cf., for example, (Machlup and Mansfield, 1983) or (Janich, 1992)) to the claim that everything in the world derives its existence from information (cf., for example, (Wheeler, 1990) or (Smolin, 1999)).

It is interesting that the area of expertise makes its imprint on the opinion of a researcher. Logicians and philosophers, who are mostly concerned with human problems, as a rule, insist that information exists purely in the human realm. Many researchers define the field of information science as limited to the human use, organization, production, and retrieval of information, excluding other information phenomenon. For instance, Barwise and Seligman write (1997) that the place of information in the natural world is far from clear.

At the same time, physicists and biologists, who know the laws of nature much better, do not agree with this opinion. Today, many scientific disciplines use the term *information* in one way or another. The term is now commonplace within a wide academic spectrum that includes astronomy, physics, biology, medicine and phisiology, psychology and the behavior sciences, economics, and political sciences. For instance, such prominent physicist as von Weizsäcker (1985) writes that information is a reflexive concept, pertaining to all sciences. He, his coauthors and followers demonstrated in the, so-called, *ur*-theory that physics reduces to information, namely, to information given by measurement outcomes (von Weizsäcker, 1958; von Weizsäcker, Scheibe and Süssmann, 1958; Castell, et al, 1975–1986; Lyre, 1998). It is done on the most basic level of elementary essences called *urs* without utilization of any specific information measure, such as Hartley measure, Shannon measure or Fisher measure.

Reading also writes (2006), "one of the main impediments to understanding the concept of information is that the term is used to describe a number of disparate things, including a property of organized matter …" He considers energy and information as the two fundamental causal agents in the natural world.

Even more radical point of view is expressed by Wheeler (1990).

"Otherwise put, every "it" — every particle, every field of force, even the space-time continuum itself — derives its function, its meaning, its very existence (even if in some contexts indirectly) from the apparatus-elicited answers to yes-or-no questions, binary choices, *bits*. "It from bit" symbolizes the idea that every item of the physical world has at bottom — a very deep bottom, in most instances — an immaterial source and explanation; that which we call reality arises in the last analysis from the posing of yes-no questions and the registering of equipment-evoked responses; in short, that all things physical are information-theoretic in origin and that this is a *participatory universe*."

Similar ideas are analyzed by a prominent physicist Lee Smolin. In his book *The Life of the Cosmos* (1999), Smolin discusses the so-called *holographic principle*, first introduced by the physicist Gerard't Hooft and later developed by many other physicists. The holographic principle exists in two forms: strong and weak. The weak holographic principle asserts that there are no things, only processes, and that these processes are merely the exchange of data across two-dimensional screens. Data are not important by themselves. Their role is to store and provide information. According to this approach, the three-dimensional world *is* the flow of information.

Based on all these approaches, Bekenstein (2003) claims that there is a growing trend in physics to define the physical world as being made of information itself.

According to Stonier (1991), structural and kinetic information is an intrinsic component of the universe. It is independent of whether any form of intelligence can perceive it or not.

Thus, we see that the whole nature is a huge system of information processes. In the information-processing cosmos, each physical situation, regardless of location, emerges from the flow of information, generates information and gives information to the environment. According to Stonier, "information exists;" that is, information exists independently of human thinking (Stonier 1997). We can see that behind each law of nature there is a program, a functioning algorithm, while, according to the contemporary theory of algorithms (Burgin, 2005), an algorithm is a compressed information representation of processes.

The aphoristic expression "*It from Bit*" (Wheeler, 1990) allows one to see the role of information from different perspectives. One of these perspectives explains that when scientists study nature, it is only an illusion that they are dealing with physical objects. Actually researchers have only information from and about these objects. In general, all people living in the physical world know about this world and its parts and elements only because they get information form these systems. In a more detailed exposition, we have the following situation.

A person (or a group) H knows about some object A only if A has a name N_A in the mind M_H of H and there are some data D_A in M_H that represent property(ies) of A. Both N_A and D_A are conceptual representations in the sense of (Burgin and Gorsky, 1991) of A in M_H. These representations are formed by means of information that comes to M_H from receptors in the nervous system or is produced in M_H or comes to M_H from other channels, e.g., electrodes, electromagnetic fields, etc. Thus, all knowledge that people have about the world they live in is the result of information reception and production. If *It* is understood as a thing and *Bit* is understood as information, then people have things, or more exactly, their representations in the mind, only from information.

Another perspective assumes that emergence of all things is caused by information processing as there are no physical or mental processes that does not include information flow. For instance, Lyre (1998) asserts that the basic object of quantum physics, the quantum wave function, is information.

One more of the perspectives under discussion conjectures that emergence of all things *is* information processing where the whole world is something like an enormous computer that "computes" all things that exist.

In essence, every scientific discipline today uses, mostly without exact definition, the notion of information within its own context and with regard to specific phenomena. Being innate to nature, information appears in different spheres of natural sciences, such as biology, "Life, too, is digital information written in DNA" (Ridley, 2000), and in physics, "Giving us its as bits, the quantum presents us with physics as information" (Wheeler, 1990) or the whole physics is derived from Fisher information theory (Frieden, 1998).

In his book "The Touchstone of Life" (1999), Werner Loewenstein persuasively demonstrates that information is the foundation of life. To do this, he gives his own definition of information, being unable to apply the conventional definition that comes from the Hartley-Shannon's information theory. Namely, according to Loewenstein (1999), "information, in its connotation in physics, is a *measure of order* — a universal measure applicable to any structure, any system. It quantifies the instructions that are needed to produce a certain organization."

Thompson (1968) asserts that "the organization is the information". Scarrott (1989) writes that every living organism, its vital organs and its cells are organized systems bonded by information.

Gibson (1966) emphasizes the importance of understanding perception of a human being or animal, writing that "perception is not based on having sensations … but it is surely based on detecting information."

Ruben (1992) asserts that for living beings, all interactions with the environment take place through the processing of matter-energy and/or processing of information.

Roederer (2005) considers different aspects of information in physics, biology and the brain, demonstrating that interaction is the basic process in the universe and discerning information-driven interactions and force-driven interactions.

Thus, in contrast to claims that information exists only in society, a more grounded opinion is that there is a huge diversity of information processes in nature, where information exchange goes without participation of humans. One of these processes is the replication of living creatures and their parts. In such a process, the cell is an information-processing system where DNA is a subsystem that contains the assembly instructions for building proteins. For instance, Schrodinger (1967) wrote that a gene is a very large information-containing molecule.

Further, DNA transmits genetic information (the symbolic genes which store genetic information) via specifically arranged sequences of nucleotide bases to proteins. This transmission is the basic process life on

Earth is built of. With very small variations, the genetic code, which is used to store and transmit genetic information, is similar for all life forms. In this sense, we can think of the genetic system and cellular reproduction as a symbolic code whose convention is "accepted" by the collection of all life forms.

Other codes exist in nature, such as signal transduction from the surface of cells to the genetic system, neural information processing, antigen recognition by antibodies in the immune system, etc. We can also think of animal communication mechanisms, such as the ant pheromone trails, bird signals, etc. Many assume that unlike the genetic system, most information processes in nature are of an analog rather than digital nature. This is not true because symbols can be represented not only on a piece of paper but also by signals, states of a system, chemical elements, molecules, electromagnetic waves, etc.

The ability to detect meaningful information is one of the defining characteristics of living entities, enabling cells and organisms to receive their genetic heritage, regulate their internal milieu, and respond to changes in their environment (Reading, 2006). Every organism and every cell is equipped with sensory receptors that enable it to detect and respond to meaningful information in its environment (Reading, 2006). These include surface receptors for detecting kinesthetic and chemical information, distance receptors for detecting visual, olfactory, gustatory and auditory information, and molecular receptors for detecting tissue, cellular and genetic information.

Information plays very important role in evolution. Csanyi (1989) and Kampis (1991) developed an elegant theory of evolution based on the concept of information. Burgin and Simon (2001) demonstrated that information has been and is the prevailing force of evolution in nature and society. Smith and Szathmary (1998; 1999) discuss evolutionary progress in terms of radical improvements in the representation of biological information.

The pivotal role of DNA for all living beings made it clear that life as a phenomenon is based on biological structures and information they contain. Information encoded in DNA molecules controls the creation of complex informational carriers such as protein molecules, cells, organs, and complete organisms. As a result, some researchers support the idea of looking at material objects as built of information. For instance, Rucker (1987) implies that it is now considered reasonable to say that, at the deepest, most fundamental level, our world is made of information.

Some researchers assume that information is a physical essence. For instance, Crutchfield (1990) treats information as "the primary physical entity from which probabilities can be derived." Landauer (2002) stresses, information is inevitably physical. However, it is more reasonable to suggest that people observe information only when it has a physical representation. For instance, information on the stock market or on the Olympic Games, as well as other information in social organization and communities, does not consist of physical messages but of their content.

All this brings us to the conclusion, expressed by Kaye (1995):

Information is not merely a necessary adjunct to personal, social and organizational functioning, a body of facts and knowledge to be applied to solutions of problems or to support actions. Rather it is a central and defining characteristic of all life forms, manifested in genetic transfer, in stimulus response mechanisms, in the communication of signals and messages and, in the case of humans, in the intelligent acquisition of understanding and wisdom.

1.4. Technological Aspects of Information

Programming today is a race between software engineers striving
to build bigger and better idiot-proof programs,
and the Universe trying to produce bigger and better idiots.
So far, the Universe is winning.
Rich Cook

Many books and numerous papers are written on problems of information technology. Here we give a general perspective on the situation and consider some of these problems.

Information plays various roles in technological processes. Information can serve to make decisions and to organize, perform and control a technological process (e.g., feedback information or control information). For instance, as Vegas and Basili (2005) write, "the main problem met by software developers when choosing the best suited testing technique for a software project is information." The technological process, e.g., computation, can work with information as a material when information is processed. Information can be input and/or output of a process, for example, in communication. Information is utilized by mechanisms and devices used in technological processes. As we know when a machine operates, it needs energy to enable it to produce, changes its states, e.g., preserve motion or stop moving, change objects on which it operates. At the same time, the machine needs information to determine what and how to produce, how and which states and objects to change. People who work with technology use diverse information to perform their functions and to control a diversity of machines, mechanisms and devices.

More over people began to understand that society in general and modern society in particular cannot exist without information and information technology. Information has become the leading and inherent component and fuel of every activity. Information processing is everywhere. As Ruževičius and Gedminaitė, (2007) describe, we hear words "information", "information society", "information management", "information processing", "information age", information economy", etc., so often that it seems that information becomes an object of a cult and information processing devices are sacred objects of this cult.

However, information technology emerged long ago. For instance, paper was invented almost 2000 years ago, but still remains our primary information-storage medium — apart from the human brain. What is new is the extent and role of information technology in modern culture and society.

Drathen (1990) implies that information has become a highly valued economic category, on par with capital and skilled labor. The collection, structuring and processing of information consequently constitute one of the focal points of business, and it is the task of process control engineering to provide adequate support for the production process in this area. The structuring of information is an essential precondition for the optimal conduct of technical processes.

Creation of information technology of our time is, may be, the most important revolution in human evolution. Now information processing plays more and more important role in life of people and functioning of society. Exclusively due to the accelerated development of the information technology, the industrial age gave way to the information age. It happened recently even in the USA where in 1991, companies for the first time spent more on computing and communications devices than on industrial, mining, farm, and construction machines. Information technology is now as critical for people and often as elusive as the air we breathe, which was discovered by scientists only several centuries ago. Information technology gives 30% of US economy growth since 1993. Information that is processed by computers and flows in different networks drives the economy, politics and social life.

Many information technologies have essentially changed and continue to change life of multitudes of people. The Internet brought the world into people's studies and living rooms. Now it is possible to go to this virtual world being on a plane or at a beach. New communication media connects people from the remotest places on the Earth. The Internet gave birth to e-commerce and e-publications. Cell phones and e-mail has become primary tools of communication. Information and knowledge management based on electronic devices, databases and data warehouses, revolutionizes business and industry. Embedded electronic devices saturate cars, planes, ships and houses. Computer-aided design (CAD), computer-aided manufacturing (CAM), computer-aided engineering (CAE), long-distance education, and computer-supported cooperative work (CSCW) drastically change how people create, produce, and use diverse things, how people work and how they study. New technologies change knowledge and abilities of people. In the 19th century, people knew that to talk to somebody, it was necessary to be at the same place with that person, e.g., in the same room. At the end of the 20th century, people knew that they can talk to those who were at the opposite side of the Earth, e.g., people who were living in USA, China and Australia were easily able to talk to one another without leaving their places of living. In the 19th century, people living in Europe knew that when they send a letter to somebody living in America, it was necessary to wait for a long time, weeks or even months, until the letter reached its destination. Now we know that when we send an e-mail from USA to, say, Argentina, it will take minutes to reach its destination.

Often, it is projected that the deployment of new information technologies can allow companies and corporations to circumvent or transcend geographical, cultural, temporal, and organizational barriers to the development and cooperation. Information technology has created the world where big companies can operate on a global scale, where it is possible to see what is going on the opposite side of the Earth, where people from distant countries, e.g., from USA and Australia, can communicate as those who live in the same neighborhood, and the whole Earth is becoming a small village. There are more and more countries where offering technological solutions to address economical, political, social, educational, and recreational problems is not only a commonplace but also a distinguishing feature of national cultures. That is why some prefer to use the term *Society Dependent on Information* instead of the term *Information Society* (cf., for example, (Malinowski, 2008)).

However, even now when everybody well understands the crucial role of information technology in modern society, the literature does not fully recognize the role of information and information technology in the maintenance and management of social and economic relationships within and among organizations (Baba, 1999). Anthropological discussions of reciprocity emphasize the importance of information as decision criteria in managing economic exchange but give limited attention to operations in which information is itself the object of exchange. At the same time, research in economics of information studies both sides of social information reality.

The development of information technology goes very fast. Performance of information processing machines and networks doubles every 18 months. It means that the progress in the next 18 months is the same as all previous progress, for example, the amount of data stored every 18 months is equal to the amount of all data stored before.

Machines form the physical core of technology. When machines were invented they performed work and produced material products. Now more and more machines produce information. Even the processes of doing some work, performing actions, and producing physical things more and more involve information processing.

As a result, technological aspects of information are discussed in various spheres and disciplines. Economic philosophy posits information as the source of value in a global economy. Business logic focuses on the accumulation, production and management of data, information and knowledge. Media, on the one hand, claim that availability and access to information technologies represent an increase in choice and freedom. On the other hand, they discuss negative impact of information technologies on individuals and society. For instance, information technologies make possible different kinds of cybercrimes, take away people's privacy, and put people at risk when machines fail or function in a wrong way. Discussions of the promises and dangers of the new information technologies, such as computers, Internet, digital imaging, virtual reality, etc., now saturate society. For instance, electronic communication brings both risks and rewards. One of the dangers of being able to store, retrieve and transmit information electronically is that the quantity of available information increases enormously and we come to the question of T.S. Eliot who wrote in "The Rock" (1934)

Where is the knowledge we have lost in information?

There is an information flooding and it is necessary to know how to regulate this process and have means for doing this. Indeed, as the theory of optimal control shows, provisioning, processing and managing big volumes of extra or superfluous information becomes harmful as it must engage available resources, such as time, computing and communication networks and devices, and people involved. This, in turn, can cause delays in decision and action, less efficient decision-making, control and operation. As Malinowski (2008) notes, in many situations, people spend too much effort searching for and then processing redundant information. As a result, they are left with too little time and other resources to perform their main functions.

The information overflow has one more negative consequence. Namely, the need to process more and more information, for example, to read a multitude of e-mails and answer to them, while having the same limited time available, people start doing many things in a loose manner (cf., for example, (Carr, 2008)). People lose some important skills and features. For instance, the majority of those who have to answer 100 and more e-mails every day cannot read long texts, such as books or even long articles. These people lose the ability of concentration. Their attention switches to something different in a short time.

This may be good and even beneficial to some professions, e.g., for flight dispatchers, but is unacceptable and even disastrous for other forms of activity. For instance, obtaining an important result in science or mathematics demands total concentration on the problem for a long time, sometimes for years. Immediate reactions may cause very bad consequences when deep analysis and deliberation are needed. For instance, when people plan operation of their companies or their investment strategy, immediate reactions can cause financial failures and crushes.

Dependence on information technologies and, especially, on computers poses many problems. It is necessary much better than now to understand what information is and how to manage it, doing this directly and not only through data management. It is necessary much better than now to understand what computers can do and what they cannot do. It is necessary much better than now to understand how to manage rapidly growing mountains of stored data and universes of computer networks.

An important problem of contemporary information technology is whether computers process only data or also information. A solution to this problem based on the general theory of information is given at the end of Section 2.5.

One of the most threatening features of the contemporary society is the common lack of ability to discriminate between useful, sound and trustworthy information and a worthless, often harmful and misleading stuff that has always been around but now with the advent of the Internet, e-mail systems and other communication tools, it multiplies with unimaginable rate. As Malinowski (2008) implies, a lot of information carrying media are full of information that is of low quality and quite often imprecise and even false. The usage of such information to achieve a chosen objective may bring and often brings unwelcome results.

There are other problems with information technology. For instance, software construction is chaotic and we are now only on the way to software engineering. Internet grows very fast and the problem of its scalability becomes very urgent, e.g., it is necessary to know how to deal with more than three billion pages of the Web. It is not just the huge number of pages and terabyte databases spreading on the Web that is the problem, but also the disorganized state of the Web itself.

One more problem is analyzed by Borgman (1984; 2000) and some other philosophers (cf., for example, (Veerbeck, 2002)). They found that technology in general and information technology in particular creates new patterns in the way people live their lives, alienating them from reality. On the one hand, technology decreases the effort that is needed to achieve definite goals. On the other hand, this disburdening character of technology changes the nature of people's involvement with reality. Technology can both enrich and reduce human life at the same time, and thus, the role of technology in the relations between people, as well as between people and reality, is ambivalent. Information technology produces virtual reality as a commodity and can be used both to substitute physical reality and mediate people's involvement with physical reality and with each other. It is possible to treat virtual worlds created by computers and their networks as a mental world of artificial information processing devices. The place of the mental world is analyzed in Section 2.1 in the context of the world structure as a whole, i.e., as a component of the existential triad.

Different researchers and philosophers write about the death of privacy due to unlimited abilities of information technology and its misuse by different people and organizations (cf., for example, (Westin, 1972; Garfinkel, 2000)).

In addition, introduction of a new information technology can create problems for work groups, organization divisions and organizations because it threatens to disrupt or even destroy the boundary maintenance mechanisms used to manage social relations between groups, divisions and organizations (Baba, 1999). Often the risk arises from special characteristics of information technology, creating a number of challenges to information control and management by work groups, organization divisions and organizations. First, electronic communication may replace traditional boundary maintenance mechanisms, making these mechanisms and the corresponding means of controlling information obsolete. Second, new information technologies may remove the control of information from the conventional place, e.g., from the local scene, and place it in the hands of other parties. Third, it is possible that new information technologies represent information in an abstract form versus a physical form, whose security is easier to protect in many cases. Fourth, the new information technology can be used to force a new type of communication between groups, divisions or organizations. In essence, people have to adjust their habits, ways of working and thinking, structures of connections and develop new skills to make new information technology efficient. Otherwise, this technology does not give a sufficiently positive result for an individual, work group, organization division and the whole organization.

To conclude, it is necessary to remark that technology is created by people. So, it is natural that the first theoretical advance and main practical achievements were related to information processes in the technological domain. The first big break-through in this area was the mathematical theory of communication (or more exactly, communication in technical systems) created by Shannon (1948).

1.5. Structure of the Book

There's only one solution: look at the map.
Umberto Eco, *Foucalt's Pendulum*

The map is not the territory,
and the name is not the thing named.
Alfred Korzybski

The main goal of the book is to achieve a synthesized understanding of the huge diversity of information phenomena by building a *general theory of information* that will be able to systematize and bind other existing information theories in one unified theoretical system. With this goal in mind, the book is organized as three-component system. At first (in Chapter 1), contemporary interpretations and explications of the term *information* are analyzed (Section 1.1) and the role of information in contemporary society (Section 1.2), nature (Section 1.3) and technology (Section 1.4) is discussed. Then (in Chapter 2), the general theory of information is presented. The third component of the book (Chapters 3–7) contains an exposition of popular and not so popular information theories. For these theories, only some basics that allow one to better comprehend a more detailed exposition are given. It provides an opportunity for the reader to understand how the general theory of information unifies existing knowledge in information studies.

From the unification perspective, the book has a three-fold purpose. The first aspiration is to present a new approach in information studies called the *general theory of information*. The second objective is presentation and analysis of existing directions in information theory and special information theories, such as Shannon's statistical information theory or algorithmic information theory, from the point of view of the general theory of information. The third aspiration of the book is to show possibilities opened by the new approach for information technology, information sciences, computer science, knowledge engineering, psychology, linguistics, social sciences, and education.

Here we do not try to represent special information theories and directions in a complete form or even to give all important results of these theories and directions. For some of them, such as statistical information theory or algorithmic information theory, complete representation demands several books larger than this one. Our goal is to give some introduction to these theories, explaining their basics and demonstrating how they can be presented as specifications of the general theory of information. Besides, references are given to sources where an interested reader can find more information about these theories.

Thus, we do not concentrate our exposition on demonstration of a series of sophisticated theorems, do not strive to describe one or two (even the most popular) ways of understanding and modeling the phenomenon of information and do not focus on giving an overview of the deepest contributions in the considered information theories. The goal is to present a broad picture of contemporary information studies, provide a unifying information theory and synthesize all existing approaches in amalgamated structure of ideas, constructions, methods, and applications.

Chapter 2 contains an informal exposition of the general theory of information and its applications to the theory of knowledge and psychology. The main result of the general theory of information is the development of the unified definition information that encompasses the enormous diversity of types, forms and classes of information. In

Section 2.1, we develop theoretical and methodological foundations for the general theory of information. These foundations include the general structures of the world, mathematical definition of the concept *structure*, and elements of semiotics, the discipline that studies signs, symbols and their systems.

Sections 2.2 and 2.3 contain basics of the general theory of information, giving its conceptual and methodological foundations. Developing the general theory of information, we utilize three levels of formalization: *principles*, *postulates*, and *axioms*. Principles represent informal assumptions related to studied phenomena, which, in our case, are information, information processes and systems. Postulates describe connections between the theory domain and theoretical constructions. Axioms characterize properties of theoretical constructions (e.g., mathematical structures) used in this theory. Thus, the base of the general theory of information is a system of principles and there are two groups of such principles: ontological and axiological.

Ontological principles studied in Section 2.2 reflect major features of information essence and behavior. They give an answer to the question "What is information?" In particular, the Ontological Principle O2 and its versions define information as a phenomenon that exists in nature, society, mentality of people, virtual reality, and in the artificial world of machines and mechanisms created by people.

Axiological principles studied in Section 2.3 explain how to evaluate, estimate and measure information and what measures of information are necessary. Studying information and related processes, researchers have invented a diversity of information measures, such as the information quantity, information value, information cost, information entropy, information uncertainty, average information score, information effectiveness, information completeness, information relevance, information reliability, and information authenticity. Axiological principles provide a reference frame for all of these measures and a guide for constructing new measures.

Section 2.4 demonstrates what kinds of information exist and how to discern them. For instance, distinctions between genuine information, false information, misinformation, disinformation, and pseudoinformation are considered. A variety of important properties of information are explicated and analyzed. For some of them, mathematical models are built. Relations between information, data, and knowledge are studied in Section 2.5. Relations between emotions and information are studied in Section 2.6.

Chapter 3 contains a brief exposition of several directions and applications of the statistical information theory. The main and most popular direction in the statistical information theory emerged as a communication theory in the works of Nyquist (1924), Hartley (1928), and was developed to a full extent by Shannon (1948).

However, even before communication engineers developed their measures of information, Fisher (1922) was the first to introduce such an information measure as the *variety of information*, giving birth to another direction in statistical information theory because his measure is also statistical by its nature. It is considered in Sections 3.6 and 7.3.3.

Relations between information and communication are studied in Section 3.1. Relations between information, uncertainty and entropy are considered in Section 3.2. The problem of the difference between information in conventional systems and quantum information is treated in Section 3.3. Section 3.4 demonstrates what relations exist between information and problem solving. Section 3.5 describes axiomatic foundations of the statistical theory of information. How theory of information is used in physics is explained in Section 3.6.

In contrast to statistical theories of information, semantic theories of information, which are described in Chapter 4, study meaning of information. In some cases, meaning of information is understood as the assumption that every piece of information has the characteristic that it makes a positive assertion and at the same time makes a denial of the opposite of that assertion. However, meaning is a more complicated phenomenon and to understand it in the context of information theory, we start Chapter 4 with a study of three communicational aspects, or dimensions, of information: syntax, semantics and pragmatics (cf. Section 4.1). Then we present semantic information theories, that is, theories that make emphasis on the semantics of information. In Section 4.2, we give an exposition of the first semantic information theory developed by Bar-Hillel and Carnap, as well as its later developments and improvements. In Section 4.3, we reflect on knowledge oriented information theories.

Chapter 5 provides a broad perspective on algorithmic information theory with its main peculiarities and constructions. In comparison with the majority of sources on algorithmic information theory, we present this theory on several levels. At first, the conventional level of recursive algorithms is considered in Sections 5.1 and 5.2. Many believe that the recursive information size (often called Kolmogorov complexity or descriptive complexity) of an object is a form of absolute information of the individual object. However, discovery of super-recursive algorithms and emergence the theory of super-recursive algorithms demonstrated a relative nature of the recursive information size. That is why the recursive algorithmic approach to information is upgraded to the next, super-recursive level of the algorithmic universe in Section 5.3. This is a necessary step as super-recursive algorithms are essentially more efficient in processing information than recursive algorithms and give more adequate models for the majority of information systems. Finally the highest, axiomatic level is achieved in a form of an axiomatic algorithmic information theory considered in Section 5.5. The results and constructions from Section 5.5 solve Problem 15 from the list of open problems in (Calude, 1996). Namely, Problem 15 asks to axiomatize algorithmic information theory. Section 5.4 contains a relativized version of algorithmic information theory.

It is demonstrated that more powerful algorithms, or a system with more powerful algorithms, need less information to do the same thing, i.e., to understand a text, to write a novel, to make a discovery or to organize successful functioning of a company. These results mathematically prove that the quantity of information a carrier has for a system depends on that system.

Chapter 6 contains an exposition of pragmatic theories of information. In Section 6.1, we consider the economics of information, which studies the role of information in the economic activity and has developed measures for estimation of the economic value and cost of information and information sources. In Section 6.2, we consider such important characteristics as value, cost, and quality of information.

Information quality, as researchers from MIT emphasize, is a survival issue for both public and private sectors: companies, organizations, and governments with the best information have a clear competitive edge. Section 6.3 contains elements of the qualitative information theory developed by Mazur.

Dynamic theories of information are presented in Chapter 7. In Section 7.1, theories of information flow developed by Dretske, Barwise and Seligman are described. Section 7.2 contains an exposition of the operator theory of information developed by Chechkin.

Section 7.3 exhibits information algebra and geometry. Elements of the mathematical component of the general theory of information are expounded in Subsection 7.3.1. This mathematical theory is based on functional models. It is also possible to develop a mathematical component of the general theory of information based on category theory.

Elements of the theory of abstract information algebras are presented in Subsection 7.3.2. Abstract information algebras can model operations and processes with information carriers, such as data, texts, and documents.

Information geometry is discussed in Subsection 7.3.3, demonstrating application of geometrical methods and structures to information studies and practice.

The last Chapter 8 contains some conclusions and directions for future research.

Exposition of material is aimed at different groups of readers. Those who want to know more about history of information studies and get a general perspective of the current situation in this area can skip proofs and even many results that are given in the strict mathematical form. At the same time, those who have a sufficient mathematical training and are interested in formalized information theories can skip preliminary deliberations and go directly to the sections that contain mathematical exposition. Thus, a variety of readers will be able to find interesting and useful issues in this book if each reader chooses those topics that are of interest to her or to him.

It is necessary to remark that the research in the area of information studies is extremely active and information is related to everything, in other words, there is nothing that does not involve the use of information. Consequently, it is impossible to include all ideas, issues, directions, and references that exist in this area, for which we ask the reader's forbearance.