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CARTOGRAPHIC MODEL OF REALITY

STRUCTURE AND PROPERTIES

OSSOLINEUM
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WYDANIE SPECJALNE Nr 7

ANDRZEJ CZERNY

KARTOGRAFICZNY MODEL RZECZYWISTOŚCI

STRUKTURA I WŁASNOŚCI

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PREFACE

In the sixties a new stage in the development of cartographic science began. The former paradigm determining the ways of stating and solving problems proved to be insufficient. Attempts have been made in cartography to take account of the results and methods of branches of modern science such as information theory, semiotics, linguistics and psychology. As a result, methodological views diverged more nad more and different research orientations in theoretical cartography appeared. Technical innovations which revolutionized applied cartography (first of all computer assisted mapmaking and remote sensing as a source of data for thematic maps) have, of course, influenced the development of theoretical concepts in cartography as well.

The traditional concept of map changes according to the adopted research orientation. And yet, two basic functions of map have remained: the one of representing known reality (modelling function) and the one of conveying information (communication function).

Map as model is the topic of the present work. The study has been induced by both cognitional and methodological considerations: (1) there are many lacunae in theoretical knowledge in this domain (Section 1.3, Map as model); (2) there exists a methodological framework which makes it possible to systematize the research findings (Section 2.1, System approach). As there are many concepts of general systems the researcher has to select the most suitable approach intuitively.

This work is based on the assumptions of the general systems theory advanced by A.I. Uyemov. In addition to this, the semiotic method is used: map is considered as a sign construction which can be analyzed by applying some concepts and interpretation schemes taken from semiotics. Three laws describing constitutive properties of map as model are formulated (Chapter 2, The theory of map as system).

The connections between cartographic model and the system modelled are explained in terms of set theory and the theory of relations (Section 2.4, Mapping of reality). In this context it should be noted that both mapmaking and the use of map are based on the assumptions that: (a) objects and phenomena represented on maps exist objectively; (b) they can be known through experience. And yet, cartographers-theoreticians accept two, apparently contradictory, views: (1) map is a model which "directly" represents a real empirical system; (2) map is the representation of an idealized model of reality (the model of lower order) and thus provides the description of an abstract system which varies from the known reality. These two views prove not to contradict but rather complement each other if the respective conditions of their applicability are considered. The first statement adequately describes a large-scale topographic map. The statement, however, proves to be too narrow to be applicable to grossly generalized maps and thematic maps which require introducing such factors as the language of description of the investigated reality and method of apprehending knowledge. In cartography, a pragmatic aspect is the most relevant: maps are the useful means of representing known reality and they can efficiently serve practical purposes.

Systemic description of map is supplemented by the discussion of its function in the process of producing cognitive information (Chapter 3, Cognitive function of map). The system of interrelated concepts worked out by the author to describe map as model is then used to give the explication of the concept of map which serves as a kind of summary conclusion of the present work.

1. INTRODUCTION

1.1. RESEARCH ORIENTATIONS IN CARTOGRAPHY

Cartography used to be a partical skill for many centuries. It estabilished itself as an independent branch of science as late as in the first quarter of the 20th century (Arnberger 1976). Cartographic investigation focused on the methods of graphic representation of mapped phenomena and the traditional approach consisted in observing and recording facts on which some generalizations were made.

Theoretical revolution in cartography which occurred in the sixties gave rise to several research orientations (Czerny 1990). The theories advanced in different branches of science and the perspectives they offered on the problems relevant for cartography have greatly contributed to the formulation of assumptions on which various research orientations in cartography rely. The difference between the traditional approach and the new orientations consists in the fact that in the latter, as opposed to the former, the course of reasoning is from the general, i.e., from the theoretical assumptions, to the particulars.

Communication orientation in theoretical cartography is based on the assumption that generalized model of communication system can be used to describe both the process of mapmaking and the process of map using, the role of both being crucial to cartographic research. Models of cartographic communication are modifications of the classical Shannon's system. They were proposed by Moles (1964), Koláčny (1969), Ratajski (1970a), Robinson and Petchenik (1976), and others. The communication orientation assumes that cartography as science deals with the commnication of spatial information by means of maps and with the transformation of that information in the process. In that orientation the most fundamental function of map consist in the fact that it is the medium of communication. The adherents of communication orientation believe that the theory of cartography should be based on information theory.

Systems-cybernetic orientation consist in the application of cybernetic methods to cartography (Grygorenko 1984). It is assumed that cartographic communication is the system of cybernetic information which can be described in exact mathematical and cybernetic terms (cf. 1.3.3).

Semiotic orientation in cartography appeared as a result of assimilating semiotic concepts and methods (cf. 2.3.1). The focus of cartographic research in that orientation is on the sign system, i.e., on the conventional code composed of sign tokens on a map. Bertin's (1967) theory of semiology of graphics in which the rules governing correct formation of some entities, i.e., map images were analyzed and explained is the most comprehensive realization of that concept.

The essence of *formal orientation* in theoretical cartography consist in the formalizing method used in logic and mathematics (Arnberger 1970). The analysis is focused on the graphic form of sign, its other features being disregarded. In that concept, the goal of cartography consists in the analysis of logical structure of cartographic signs as formal signs, i.e., the ones which bear no meaning.

Linguistic orientation draws on linguistic structuralism and assumes that the cartographic language bears analogy with natural language (Pravda 1982). In this concept the application of the verbal language analysis is extended to cartographic signs, regarded as linguistic expressions equivalent to words and sentences.

Cognitional orientation competes with the communication orientation. The adherents of the former consider that the method of theoretical cartography is founded on the philosophical theory of reflection (Salichtchev 1977, Ogrissek 1987). According to that concept, cartography is the science which investigates the processes of cognizing reality by means of maps. Map is considered as the model of reality, the model reflecting that reality adequately. Acquiring new knowledge about reality from map is regarded as the most essential function of a map.

From the point of view of the epistemological principle of complementarity formulated by N. Bohr, the contradictions between different research orientations are only apparent. Their value consists in the fact that they provide new conceptual tools which make it possible for cartography to go beyond its traditional domain and simultaneously produce comprehensive (complementary) descriptions and explanations.

1.2. THE CONCEPT OF MODEL

The term "model" used in different spheres of human activity (e.g. in arts, technology, mathematics) bears different meanings. This stems from the fact that terminological conventions in those domains are different. The resulting ambiguities disregarded, this analysis will centre on the methodological concept of model.

If an object is to be investigated, then – in methodological terms – the task may be performed in two ways: either by investigating the object itself, or its model, selected or producted with the aim of replacing the object. In the latter case, the statements pertaining to the original are derived, according to certain rules, from informative statements about the model (Zinovyev 1976). Thus, in general terms, model can be defined as an object which is investigated to obtain information about another object. Different kinds of objects may constitute models, e.g. physical objects (a representation of something with the use of reduction scale) or mathematical objects (the system of equations describing some phenomenon).

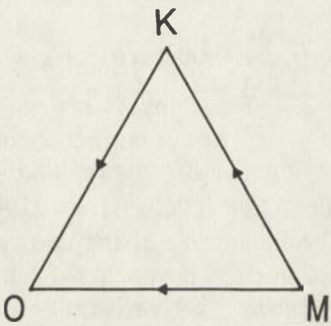


Fig. 1. Cognitive relation

O – object (known), *M* – model, *K* – knower

A three-place cognizance relation holds between model *M*, the knower *K*, and the cognized object *O* (fig. 1). The relation "*M* is the model of *O*" is a relative product of the relation "*M* is investigated by *K*" and the relation "*K* gains information on *O*", i.e., *M* is the model of *O* if and only if there is such a knower *K*, that *M* is investigated by *K*, and at the same time, *K* gains information on *O* (and if, of course, $M \neq O$). Evidently, in that sense, maps are models.

Logically, the method of investigating objects by means of their models is based on *analogical inference*. If relations between two objects are rather distant, the concept of analogy tends to be used. If, however, similarity between a model and the object modelled (original, prototype, correlate) is close, it can be expressed in the form of mathematical relations, such as isomorphism and homomorphism. Then the reference is made to isomorphic, homomorphic or other models (cf. 2.4).

In general terms, two views on the relationship between the knower and the cognized object can be distinguished: realism (materialists are among its adherents) and idealism (the concept advanced by Kant). As a consequence, there are at least two ways of comprehending the term "correlate of a model": (1) the term denotes a fragment of objective reality – the thesis of realism; (2) the term denotes subjective reality, i.e., some mental construction – the thesis of idealism.

Building and researching models in many branches of science have a long-standing tradition but universal scientific interest in models developed as late as in the sixties (Witt 1976). The beginning of research into models, conducted on the grounds of the methodology of sciences, coincides with the emergency of cybernetics. According to Shtoff (1966), the article by A. Rosenblueth and N. Wiener "The Role of Models in Science", published in 1944–45 played a precursory role.

1.3. MAP AS MODEL

1.3.1. INTRODUCTORY REMARKS

The first writers who noted that maps are *sui generis* models were not cartographers but the authors of works on methodology of sciences (cf. Koen 1968, Aslanikashvili 1974, Ostrowski 1984). The publications by Stefanov (1964), Board (1967), Salichtchev (1967), Koen (1968), Aslanikashvili (1968) and Stams (1971) mark the beginning of the cartographers' interest in those issues. Two different theoretical approaches to the problem of model in cartography can be distinguished. The thesis that map is a model has now been accepted both by the supporters of cognizance orientation and the supporters of communication orientation. The representatives of cognizance orientation, (K.A. Salichtchev, B. Koen, A.F. Aslanikashvili, A.M. Berlyant, R. Ogrissek), however, think that the essence of the problem consists in the fact that cartographic model is the *medium of cognizing reality*. The cartographers from East European countries who represent this approach had been inspired by the Soviet philosophical writigns on models, particulary by th work of a marxist philosopher Shtoff (1966), whereas the cartographers representing communication orientation (C. Board, G. Hake, A.S. Vasmut, W. Ostrowski, J. Krcho, W. Grygorenko) regard cartographic model as the *medium of communication*. In the following, theoretical findings concerning maps as models will be briefly discussed and definitions and principal theses pertaining to the topic presented.

1.3.2. CARTOGRAPHIC MODEL AS THE MEDIUM OF THE COGNITION OF REALITY

The origins of the first of the above mentioned orientations can be traced back to the contribution by N. Stefanov (1964) published in Bulgarian language. It was then echoed by Koen's paper, presented at the ICA Conference held in New Delhi in 1968. Stefanow argued that the problems of models and modelling addressed by philosophy should draw the attention of cartographers and conversely, the problems addressed by cartography should attract the attention of the philosophers who take interest in models and modelling. The author called map a "cartographic model" and defined it as "essential-phenomenological construction composed of graphic elements combined either overtly or convertly with the system of mathematical elements and expressed by specific means of representation".

B. Koen (1968) characterized maps as: (1) sign models; (2) information models; (3) isomorphic models; (4) coded models.

A.F. Aslanikashvili is the author of the general theory of cartography first published in Geogrian language in 1968 and subsequently in Russian language; the theory was called "metacartography" (Aslanikashvili 1974). Three principal theses of his concept are as follows: (1) the totality of objective relationships which hold between objects in connection with their spatial distribution constitutes the object of cognition in cartography; (2) cartography has its own research method – the method of cartographic modelling of spatial relationships and it uses a specific language – the language of map; (3) cartography has its own metatheory, based on the marxist theory of knowledge.

Aslanikashvili (1974) defined cartographic model as "...an ideal--and-material, symbolic, spatially similar model", block diagrams, relief models and globes being also ranked among cartographic models.

K.A. Salichtchev (1967) described cartographic representations as models of reality used not only as the media of communication, but primarily as the means of acquiring new knowledge. In the first edition of his textbook entitled „Kartovedeniye" he defined cartographic representations as "...ideal, spatial, pictorial-symbolic models of specific kind that reproduce some aspects of objective reality" (Salichtchev 1976). In the second edition he gave a new definition of map: "flat, pictorial-symbolic, spatial-and-temporal models of geographical systems and the elements of those systems" (Salichtchev 1982).

A.M. Berlyant (1973) identified a set of properties which differentiate maps from other models: (1) abstraction; (2) selectness; (3) synthetical nature; (4) scale and measurableness; (5) graphicness; (6) the quality of giving a general view of a region; (7) geometric similarity meant as graded property; (8) geographical correspondence; (9) logical nature of the legend which states how phenomena have been classified and ordered; (10) formalism – the main drawback of map.

B. Ogrissek's views (1987) are similar to the ones expressed by the Soviet cartographers.

1.3.3. CARTOGRAPHIC MODEL AS THE MEDIUM OF COMMUNICATION

C. Board (1976) characterized maps as tools of geographic investigation which he considered – under Moles' (164) influence to be the medium by which spatial information is communicated. At the same time he described maps as iconic conceptual models of the real world. That concept has probably been put forward under the influence of the so-called model-based paradigm which was connected with quantitative revolution in geography in the fifties and sixties. It consisted in the application of statistical and mathematical methods to modelling of spatial structures, i.e., the structures which constitute objects of geographical research.

The analogies between the concepts of model in geography and in cartography are, however, limited. W. Witt (1976) pointed out that substantial differences exist between maps and theoretical models. In geography such models are the forms in which the theory of investigated system is represented, and in most cases these forms are mathematical whereas maps, in his opinion, are inductive iconic model.

W. Stams (1971) analyzed properties of maps regarded as "geographical stores of information" and concluded by giving the following brief definition of map: "scale graphic model of geographical reality (geographical space)".

G. Pápay (1972) compiled a list of properties which are characteristic of cartographic representations regarded as the models of a specific type which: (1) are models of structure; (2) represent spatial structures more adequately than any other models; (3) preserve spatial similarity; (4) represent the systems on the surface of a celestial body or the systems composed of many celestial bodies; (5) perform the roles of: explicating representation, communication and acquiring information.

G. Hake (1974) analyzed the relations between information sets contained in the primary, secondary and tertiary models (a tertiary model is the image of an object, evoked by its model in the map user's mind). The original model is the result of direct observation of the real world, whereas cartographic representation is always the product of transformation of the original model. Maps were defined by him as "secondary, graphic models of reality".

E.E. Shiryaev (1975) gave the following characteristics of map: (1) the type of model to which map belongs is an intermediate type between physical model and mathematical model; (2) map belongs to symbolic models; (3) map is a graphic-mathematical model; (4) map as model preforms cognitive as well as informative functions; (5) map is a static model.

A.S. Vasmut (1979) considers general map as "symbolic, spatially similar model of countryside". Given that definition of map he indentified its six main properties: (1) it is a spatial model; (2) essential properties retain similarity; (3) it is model of structure and it performs the role of acquiring new knowledge; (4) it is a material-symbolic model; (5) it is many-to-one mapping of the Earth surface; (6) it is a static model.

W. Ostrowski (1979), while analizing the criteria of maps evaluation, described maps as: (1) logical-graphic models; (2) spatially-similar sign models; (3) pictorial-conceptual models.

J. Krcho (1981), using symbolic language, considered map as an abstract cartographic model which represents a real spatial system (geographical landscape). In that representation a set of cartographic words, i.e. symbols are associated with the elements of real system and the relationships between them. Each cartographic word consists of a symbol and the location to which it has been assigned. According to Krcho, cartographic model and the real system are associated by the homomorphic relation.

W. Grygorenko (1984) presented his cybernetic concept of cartographic communication: $KK=\langle R_S, I', R_M\rangle$, the third of the listed elements, besides sender R_S and the informing activity I', being the cartographic image R_M as a material model of reality.

The end of the twenty-five years period in which models became the object of interest in cartography was marked by Ch. Steurer's work (1989) which presented some implications for cartography as science of the philosophical proposition according to which model-building is implicit in the acquisition of any kind of knowledge. The author proposed the following definition of the concept of the map: "Map is a model of the structure of the spatial information about realities" (he referred to subjective realities such as mental maps). Then he listed the following properties of maps as model: (1) in terms of set theory, they map relations and properties of the original; (2) maps reduce the quantity of relations and properties of the original preserving only the ones which are essential (to the mapmaker or the user of map); (3) maps are pragmatic objects as they are performing the function of substituting an original (reality) thanks to somebody, for somebody in a definite time and with a definite purpose. To Steurer, the way in which the reflection theory interpreted the relation between map and reality was quite unacceptable and he rejected it by arguing that the "original" is but the knower's own construction.

1.3.4. SUMMING UP

The intension of the concept of the map, formed on the grounds of traditional cartography, was usually broadened by those cartographes who considered map to be a model. But the research on cartographic modelling failed to produce sufficiently coherent and comprehensive answers. Whereas in theoretical cartography a "communication paradigm" could already be indentified, in research activity a similar "model paradigm" has not been established yet. Such a paradigm (i.e., a set of convictions, assumptions, and patterns) defines ways and means of the solution of problems following from the application of that paradigm to the investigation of facts relevant to cartography and the relationships between them.

In the works representative of cognitive approach the discussion of theoretical foundations, including purely philosophical elements, typically predominates over the empirically verifiable elements. On the other hand, in the works representative of communication approach the role of map as model is defined as secondary.

Some features which different authors ascribe to cartographic models apparently contradict each other, e.g., materiality and ideality, iconicity and symbolicalness. No satisfactory answer has been given to the question concerning formal properties of similarity relationships which associate map and the reality. The concepts of isomorphism and homomorphism employed in the discussion by cartographers used to given a very liberal interpretations. The definition of properties and the structure of map as model should be comprehensive, systematic, adequately substantiated and based on clearly formulated methodical assumptions.

2. THE THEORY OF MAP AS SYSTEM

2.1. SYSTEM APPROACH

The concept of system usually denotes a set of elements which are interrelated and constitute a certain whole. According to Uyemov (1977) that definition is too broad as it does not suffice ascribe some relationships nad properties to a complex object to define it as system. For instance, if a child or another person who knows nothing about maps sees a map, the map will be perceived by him or her as a chaotic collection of points, lines and patches. That person will be able to indentify different properties of the element of the drawing (shapes, colours etc.) and relationships between them (e.g., the position of one element relative to another) but it will not possible for him or her to comprehend that the same collection of points, lines and patches is a system unless he or she knows that some relationships on the drawing correspond to the relationships between certain objects on the surface of the Earth.

In terms of logic, the existence of elements, properties and relationships is a necessary but not sufficient condition to the existence of a system. Apart from that, a higher level relation between those elements, properties and relationships must be defined. Uyemov explicated the concept of "system" by analyzing and generalizing the logical structure of several definitions of system, formulated in various branches of science. The conceptual framework of his general systems theory comprises three fundamental categories: "object", "property" and "relation". The categories of definite and indefinite objects also play an important role in his definition of system (Uyemov 1971, 1977, 1978).

The definition of system is dualistic as the author formulated two versions of the definition and argued that they are equivalent, i.e., if an object is a system by one of the two definitions, it will also be a system by the other definition.

Definition 1:

Any object within which there holds the relation a property of which has already been defined is a system.

Definition 2:

Any object whose certain properties are associated by the relation which has already been defined is a system.

Both definitions can be presented in the form of the formulae in which the following symbols are used: "M" stands for an object, the symbol of relation "$R(M)$" being on the left of the symbol M, and the symbol of property "$(M)P$" being on its right. The expression "$(M)S$" means that object M is a system.

(1) $$(M)S=[R(M)]P$$

(2) $$(M)S=R[(M)P].$$

In system analysis the term "object" is used in a very broad sense and can denote anything that has been selected as the object of research. A class of individual objects, e.g. the class of Polish cities, may be the object of research. Also, an individual object (e.g., Warsaw) may be a system, if it has been represented by a collection of its constituent parts, i.e., an aggregate. Theoretically, the relation $R(M)$ may be reflexive if that relation holds between object M and itself. It follows from the above that a system needs not be composed of elements.

Either the variable P or R, outside the square brackets, expresses a definite property or relation, i.e., the property or relation which has already been defined and which constitutes the system. The choice of values of that variable tends to be rather free and depends on the nature of scientific research or on some practical considerations.

Not every relation on a set of elements creates a system. A large collection of maps in a library may serve as an example. That collection must be classified to be usable. In terms of logic every equivalence relation defined on a set splits that set into subclasses, e.g., identity relation of map cover colours in that collection of maps. It is evident that on such a casually chosen relation no map systematization of theoretical or practical significance can be based. Inappropriate selection of the criteria, and consequently, of the equivalence relations estabilishing partition of that set, would result in chaos rather than in the systematization of maps. This has been evidenced by a number of works devoted to the principles of maps classification (e.g., Uhorczak 1976).

2.2. THE FIRST METHOD OF DESCRIBING MAP AS SYSTEM

Map can be described as system in two ways. In the first case the reasoning will follow the sequence: $R \to P \to M$, i.e., it will proceed from the relation R constituting the system, through properties P, to the elements of system M. In the second case the reasoning will follow the sequence: $P \to R \to M$, i.e., from the property P constituting the system, through the relation R, to the elements of system M. These two procedures may complement each other.

Map as model is the product of a complex rational action. The *meaning* of this action is mapping the known reality into graphic substratum. That mapping is the basis of rational knowing and action. The map is *researched* by a user. Map user analyses the map visually, makes the measurements on the map, etc. in order to obtain information on the set of components of the reality known.

Choice of relation constituting system R should meet the condition that the association between properties P, attributed to the elements of system M, and the appropriation of that system should be expressed by that relation. As it follows from the above, constituting relation of the system must correspond to the cognitive function of the cartographic model. The above condition is satisfied by the relation of mapping of a definite fragment of reality, i.e., on a set of objects which have different properties, are associated by relations and constitute different sets. The relation may be called the relation of cartographic modelling.

The relation of cartographic modelling is a complex assigning relation. It is composed of the complexes of relations K_1, K_2, ..., K_n. Each complex of relations consists of one assigning relation and a pair of comparison relations: $K_i = \langle R_i, S_i, S_i' \rangle$. Comparison relations occur between properties of graphic elements of map as well as different properties of the objects mapped. The following pairs of comparison relations can serve as examples: "on the right" and "to the East", "larger" and "more numerous". Thus, the associations between graphic elements, similar to the associations between objects of the reality known are show on a map. The relation of cartographic modelling has the following characteristics:

(a) the positional relationships between symbols located on the map plane always correspond to the relationships between respective objects located on the Earth's surface.

(b) the remaining relations between symbols on the map and between their properties may be the expressions of different relations between mapped objects.

The relation constituting the system R having been defined, the property P, relevant for that relation, should be identified. The complex of properties $(M)P$, interrelated by the relation of cartographic modelling R, is the set of the so-called distinctive features of cartographic signs.

Any feature that differentiates one sign from another is distinctive. That concept originated in linguistic structuralism in the thirties, but at present it is applied not to the linguistic signs, i.e., phonemes and graphemes alone, but to the signs in general. Each differentiating element in the system of graphic signs is its *distinctive feature* (Lyons 1977, Sebeok 1986). In cartography synonimical terms "distinctive unit" (Schlichtmann 1982) and "distinctive mark" (Robinson et al. 1984) have been used.

The set of distinctive features of cartographic signs consists of some families of features[1], including the two-dimensional feature of *location* on a plane and graphic properties of symbols such as *shape*, *size*, *orientation*, *colour*, *value*, and *texture*. The above mentioned kinds of distinctive features

[1] For the concept of a kind (a family) of properties, see: Ajdukiewicz (1974).

correspond to visual variables distinguished by Bertin (1967) and quoted in modern cartography textbooks. The mathematical term "variable", used by Bertin, implies that each member of a given set of features (e.g., shape, colour, etc.) may take any value from its respective set.

According to the theory of relations, distinctive feature of each kind (shape, size, colour, etc.) establishes an *equivalence relation* that holds between two signs if and only if they have the same feature. For instance, equivalence relation holds between sings of the same shape. Any kind of features on whose members solely equivalence relation can be estabilished is called *qualitative* or *nominal*. Examples of such features are shape, colour and orientation.

The families of features such as value, texture, size and location are ordered. The relation which orders particular features of a given kind also *partially orders* the set of signs whose members possess that feature. For instance, a relation which *linearly orders* the set of all tints of colours from white to black. At the same time, the set of signs is partially ordered, i.e., the signs which have identical values are not ordered. The families of features can be said *ordinal* if only the order of the particular features, i.e., value and texture is established.

Distinctive features such as size and location are not only ordered. Operations can be performed on the sets of those features which result in assigning a definite numerical quantity: a sum, a difference or a quotient, to two features of the same kind. Both kinds of distinctive features may be the objects of measurement. Size and location are two classes of *quantitative* features.

This presentation of distinctive features reflects the present state of knowledge in the domain of map semiotics. The above does not imply that the list of distinctive features quoted is unchangeable. First, as it is known, colour is characterized by three parameters: hue, lightness and saturation (see Robinson et al. 1984). J. Bertin replaced two of these parameters: lightness and saturation with the sole parameter of value. Secondly, contradictory views are expressed on the feature which is called either texture, spacing, grain or pattern by different authors (cf. Bertin 1967, Robinson et al. 1984).

The third stage in describing a cartographic model as system consists in identifying a set of elements *M* which have the features *P*. A clear distinction between the concept of sign type and the concept of sign token should be made now (cf. Lyons 1977). *Sign token* is a unique individual sign which occupies a definite position on a map, bears definite graphic features and denotes a definite real object, whereas *sign type* is a set of all the sign tokens of an identical graphic form. Otherwise, the difference between tokens of the same type refers to the two-dimensional feature of location on the map plane, their remaining distinctive features being identical. For instance, the sign of the post office (schematic drawing of an envelope) on the city map of Warsaw occurs in eighty-five tokens differing only with respect to the feature of location whereas the sign of an international airport (an airplane) has only one token. As it follows from the above, the set of elements of map *M* contains all the sign tokens on that map.

To sum up, it can be stated that a cartographic model is a system defined by the following formula:

$$(M)S = R[(M)P],$$

where: R denotes the cartographic modelling relationship; $P=\{P_1,...,P_n\}$ is the set of distinctive features to which sets of features such as location, shape, size, orientation, value and texture belong; M is the set of all the tokens which are constituting elements of the map. Thus, the set M of the tokens which are elements of cartographic model is a system as distinctive features P of those elements are associated with the features of the elements of the reality mapped by estabilished relations.

2.3. THE SECOND METHOD OF DESCRIBING MAP AS SYSTEM

2.3.1. INTRODUCTORY REMARKS

Although map has been described as a system in which the cartographic modelling relationship is a constitutive relation, this does not exhaust further discussion of cartographic model as system. System approach, based on the already quoted formula $P \rightarrow R \rightarrow M$ should be useful.

The second method of describing map as system boils down to defining the feature P constituting the system and characterizing the structure of map. This tantamount to the condition that relations $R(M)$ constituting the system must correspond to the feature P which has already been defined.

Map, considered as system, should seek a definite goal. The function of map as model is to give information on the reality mapped. Thus, the quality of *efficient performing the cognitive function* is a constitutive property of the system. The structure of the system $R(M)$ includes the set of those relations between the elements of cartographic model which satisfy the above mentioned requirement most efficiently.

As signs are the elements of cartographic model the relations constituting the system can be best analyzed in terms of semiotics, i.e., the theory which describes and explains relationships between signs. The concept of a *sign* is interpreted as follows: A is the sign of B if $A \neq B$ and if A is used by someone to represent B (Pelc 1982).

The meanings of some other semiotic concepts should be explained as well. The object represented, i.e., signified by a sign is called its *denotatum*. Every sign token has exactly one denotatum, whereas sign type, i.e., the set of sign tokens, is referred to the class of objects. The *meaning* or a connotation of a cartographic sign is either a specific property or a set of properties of all the denotata of the sign. For instance, the meaning (connotation) of a cartographic sign – a small red square is a property whose correspoding predicate is: "x is a city with the population number of over one million".

Semiotics classifies relations between signs, signified objects nad sign users into three classes: (1) *syntactic* relations, i.e., all the relations between a sign and the other signs; (2) *semantic* relations, i.e., the relations between sings and object signified; (3) *pragmatic* relations, i.e., the relations between a sign and its users, i.e., its sender and its recipient. The above distinction, suggested by C. Morris, is prevalent in cartographic writings, but it is not used consistently. Aslanikashvili (1974), followed by other Soviet cartographers, unfoundedly reduced the range of the concept "syntactic relations" to the relationships of the location of tokens on a map. Freytag (1971), Aslanikashvili (1974) and Pravda (1980) call the relations between signs and their denotata "sygmatic" and confine applicability of the term "semantic relations" to the relations between signs and their meanings. In fact, both kinds of the relations: sign-denotatum (i.e., sygmatic relations) and sign-meaning belong to the class of semantic relations.

The examples given in the above quoted works refer solely to semiotic relations between signs and fail to explain which of them are the most significant for the cognitive and communicative functions of a map. Later in this work an attempt will be made to answer the question which semiotic relations between the elements of the set of the signs on a map may be the most efficient means of imparting knowledge of reality.

2.3.2. SYNTACTIC RELATIONS

Syntactic relations between cartographic signs cannot be considered out of connection with their syntactic structure, as syntactic relations always hold between signs which have definite forms and are composed of definite elements.

As every sign is composed of *distinctive elements* it can be defined as an aggregate[2] or a complex of those elements. Every component of the system of graphic signs, i.e., the element which differentiates one sign from another can be a distinctive element. Any of such graphic elements of a cartographic sign can be replaced by another element ranked with the same category and this may lead to the formation of a new sign. As is known, distinctive function can be performed by sign attributes (distinctive features) such as shape, orientation, colour, texture, value, size, and in the case of a sign token, by two-dimensional feature of location on the map plane.

Planarity is characteristic of graphic representations which means that signs constitute a two-dimensional configuration, whereas other sign systems constitute a sequence, i.e., a linear succession of signs in time or in space. Linear syntactic order is characteristic of non-graphic models of reality which can be built either with the use of natural, spoken or written language (verbal descriptions) or with the use of constructed languages of mathematics, formal logic or chemical symbols, etc. Syntactic structure is the basis of identifying

[2] Aggregate is the mereological class, i.e., a whole consisting of some elements, regarded as parts of that whole.

graphic signs as a specific subset of visually perceptible signs. Cartographic signs have the same material substratum and they are formed of the same elements which are used to form graphic signs of every kind.

The following groups of syntactic relations between the elements of the set of sign tokens on a map can be identified: (a) relations among locations of tokens, i.e., of their configuration on the plane of a map; (b) another relations, i.e., non-spatial relations such as equivalence relations, ordering relations, quantitative relations, etc. Figure 2 shows the most significant binary and ternary relations among locations of tokens.

Equivalence relations among elements of a set of tokens on a map split the set into classes of similar elements. Examples of such classes are tokens of the

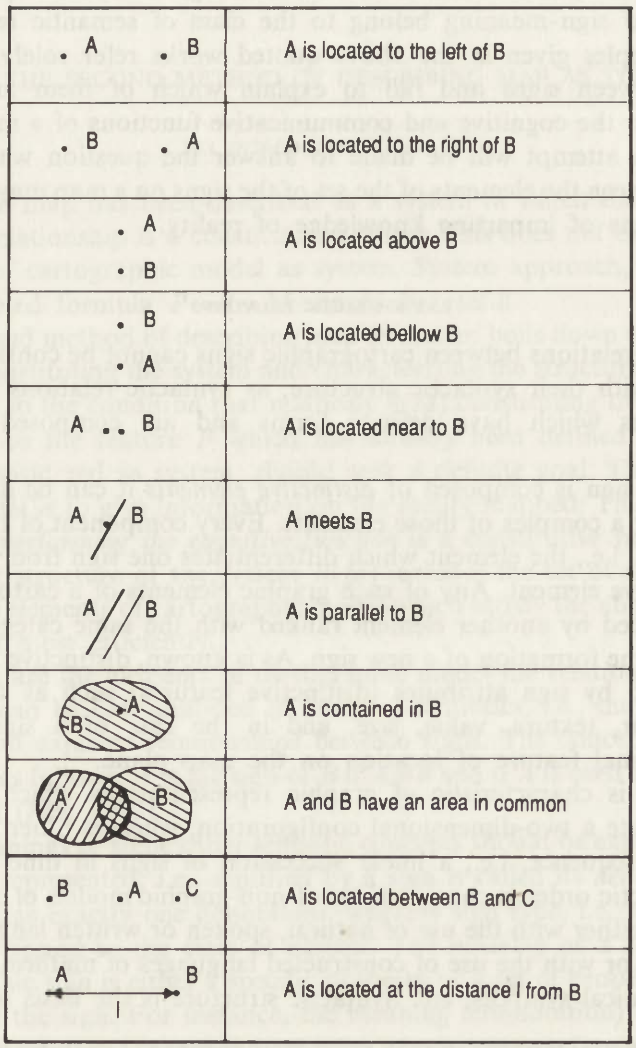


Fig. 2. Positional relationships on the map plane

same shape (e.g., graduated circles and graduated squares), of the same colour (e.g., blue drawing of hydrographic network representation and brown drawing of land relief representation) or the tokens of equal size (e.g., large point symbols representing bigger industrial centres and small point symbols representing secondary centres). Equivalence relation associates the sign tokens which are the elements of the same class and whose certain graphic elements are similar. The difference relation between tokens which are elements of different classes, for instance the tokens of different shape, size or colour is complement of the equivalence relation. Identity relation is also the equivalence relation between two or more tokens which do not differ from one another. Tokens of the same type are identical, because all the graphic elements of those tokens agree.

Ordering relations occur in the process of symbolization of ordinal information. Examples: (1) the relation "bigger" orders the set of symbols located on a graduated symbol map; (2) the relation "lighter" orders the set of colours used on a choropleth map or on an isarithmic map; (3) the relation between two symbols if visual weight of the first symbol is greater than of the second one orders the set of point symbols used to represent settlements; (4) the relation "thicker" orders the set of the line symbols used to represent main roads, secondary roads and other roads. A set of sign types is always linearly ordered whereas the set of sign tokens is partially ordered. This means that two tokens of the same type are indistinctible in respect of the partially ordering relation.

What is meant by *quantitative relationships* between signs are mainly the ratio of graduated symbols areas: $r = P_1 / P_2$ and the difference in height of bar graphs: $d = h_1 - h_2$. Ratios can also be set between the areas of two area symbols or between the lengths of two line symbols.

The kinds of syntactic relations listed above are significant for the cognitive function of a map as they are used in mapping the relationships between the object in graphic substratum. In other words, the relationships existing in reality are mapped on the set of syntactic relations. Not only does each sign signify something, but also the relations between sign types and their tokens express[3] some meanings.

2.3.3. SEMANTIC RELATIONS

The concept of *sign motivation* is connected with semantic properties of a sign (Guiraud 1971). If there is analogy between sign and the object designated, i.e., if they display any perceptible similarity, then their relationship is regarded as motivated. That similarity can be either external or internal. External similarity is the visual similarity between sign and its denotatum, whereas

[3] A term used to denote a semantic function of map, performed by it in relation to mapped reality. The term "expreess" is also used for a pragmatic function of the sign consisting in expressing some subjective experience of its user.

internal similarity is abstract and regards internal structure of sign and its denotatum.

The type of the so-called *iconic signs* is distinguished on the grounds of similarity, particularly of the visual similarity between signs and objects. Iconicity of sign can be graduated as that property is based on similarity relationship between things which have some features in common. The objects compared may be more or less similar depending on the number of properties they have in common. A colour aerial photograph of the Earth's surface shows the greates similarity to the original as regards colouring, differentiation of value and the configuration of coloured patches. Black and white panchromatic photograph is iconic to a lower degree. Multispectral scanner image preserves but one property of the original, i.e., the configuration of the image elements.

It can be said that iconic sign and its denotatum are associated by *iconic relationship*, or that the sign performs *iconic function*. The relationship between sign and its denotatum may also be unmotivated, i.e., estabilished arbitrarily regardless of any similarity between them. In that case, *symbolic relationship* occurs, i.e., the sign performs *symbolic function* and, therefore, it can be called a *symbol*.

In cartography, modes of reference have not been discussed throughly. The textbook by Robinson et al. (1984) lists three classes of point symbols: pictorial, associative and geometric. Ratajski (1973a), Hake (1975) and Salichtchev (1982) used the term "symbolic point signs" to denote associative symbols in conformity with the established tradition of German cartography.

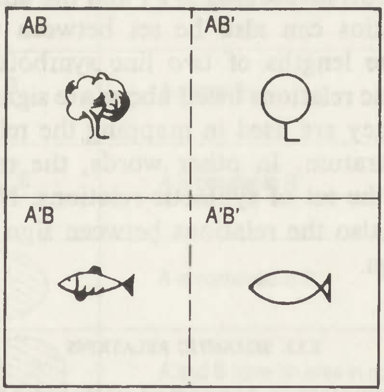


Fig. 3. Iconic and pictorial point signs

A – iconic sign, *A'* – non-iconic sign, *B* – pictorial sign, B' – non-pictorial sign

The classification presented above is deficient in terms of semiotics. This is amply shown by figure 3 presenting the classification of point signs. That figure shows four signs representing different classes of signs. Two of them depict and simultaneously designate a single deciduous tree, the form of the first sign being intricate (realistic, pictorial) and of the second one – simplified (stylized, schematic, abstract). The remaining two signs depict a fish, but designate fisheries on the map. The first sign in that pair of signs also has an intricate form, whereas the other has a simplified (abstract) form. The horizontal full line, separating point signs of two kinds reflects basic classification of signs into the iconic ones (A) and non-iconic ones (A′), i.e., symbols. Both point signs reffering to fisheries are members of the class of symbols as they do not depict their denotata. In terms of semiotics, they can be called *iconic symbols*, i.e., the signs which originally are iconic, but which actually perform the function of symbols. For instance, the iconic sign depicting a fish, symbolizes a fishery on the map. Iconic symbols can be said to have metaphoric meaning which is different from the literary one. There is no permanent connection between a symbol and its denotatum, and this applies to iconic symbols as well. Textbook classification of point signs, symbolized by the vertical broken line on the figure is superficial (formal) and fails to reach the essence.

Point signs should be first classified into iconic signs and symbols, i.e., arbitrary signs. The second class of point signs contains both iconic and *non-iconic symbols*, i.e., geometric, literal and numerical symbols. Further classification may be done according to the forms of drawing. On the basis the following kinds of signs can be distinguished: pictorial (or realistic) signs and abstract signs whose drawing is stylized. This, in fact, is not a clear-cut classification, but rather a typology.

The following classification of point signs is proposed now:

1. Iconic signs
   1.1. Pictorial iconic signs
   1.2. Abstract iconic signs
2. Iconic symbols
   2.1. Pictoral iconic symbols
   2.2. Abstract iconic symbols
3. Non-iconic symbols
   3.1. Geometric symblos
   3.2. Alphanumerical symbols (letters and numerals)

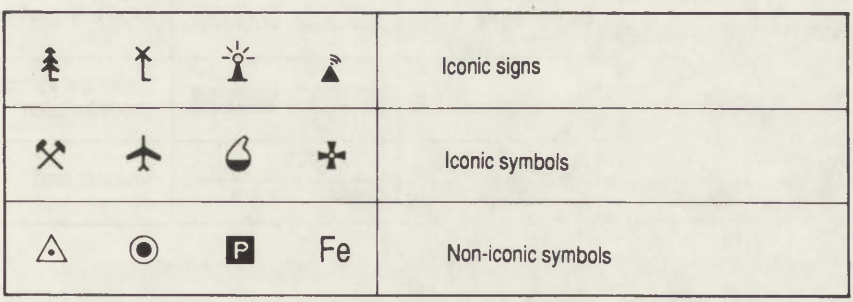


Fig. 4. Some examples of three classes of point signs

	Kinds of signs	Distinctive graphic element	Examples of signs	Meanings
Point signs	Geometric symbols, dots and graduated symbols	Shape		Iron, salt
		Texture (grain)		Iron, cobalt
		Orientation		Iron, marble
		Value		Iron, nickel
		Colour	Blue, Green	Iron, zinc
	Alphanumeric symbols	Shape	Fe, S	Iron, sulfur
Area signs	Patterns, symbol screens and colours	Shape		Kazakhs, Yakuts
		Orientation		Corn, wheat
		Value		Industrial areas, residential areas
		Colour	Blue, Green	Jurassic, Triassic
	Letters used as patterns	Shape	TTTTTT TTTTTT, Fe Fe Fe Fe	Tobacco, iron
Line signs	Line symbols	Shape		Gas pipeline, crude oil pipeline
		Texture (grain)		Exports: Wheat, rice
		Value		Passenger transport, goods transport
		Colour	Black, Red	Railroad, road

Fig 5. Symbolic function of signs: non-iconic symbols

Figure 4 presents typical examples of signs and symbols divided into three main classes of point signs.

Figures 5–9 represent an attempt in ordering cartographic signs according to their main two semantic functions, i.e., the symbolic function and the iconic one. Each sign is a combination of different graphic elements which implies that both symbolic and iconic elements can be combined to form a single sign.

Figure 5 exemplifies symbolic function of different graphic elements. Those purely symbolic sings are called non-iconic symbols. Their graphic form has been decided upon arbitrarily, as a consequence, they do not display any perceptible similarity to their denotata. This makes them similar to graphemes (letters) or symbols used in other branches of science, e.g., in chemistry, mathematics, etc.

Shape and texture are the elements of symbolic signs which originally performed iconic function (cf. Pelc 1982). Also point signs and linear signs, whose associations with designated objects are based on non-optical colour attributes, have been ranked among iconic symbols. The most significant distinctive element of such a sign is its hue which associates with various sensations such as, e.g., heat – cold, dryness – wetness, etc. (fig. 6).

Kinds of signs	Distinctive graphic element	Examples of signs	Meanings
Point signs	Shape		Seaport, airport
	Texture (grain)		Timber, textile industries
	Colour	Brown Red	Timber, iron industries
Area signs (symbol screens and colours)	Shape		Coffee plantation, coniferous forest
	Colour	Orange Green	Desert, temperate climates
Line signs	Colour	Blue Red	Cold, warm currents

Fig. 6. Symbolic function of signs: iconic symbols

The next three figures show a variety of iconic functions performed by cartographic signs. The examples of signs which display similarity to their denotata with respect to their outward appearance have been presented first (fig. 7). The hue of point signs is of the secondary importance. For instance, the function of hue used on a tourist map for the point sign denoting a tree

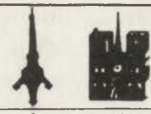
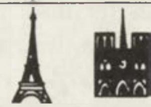
Kinds of signs		Distinctive graphic element	Examples of signs	Meanings
Point signs	Individuating pictorial (intricate) signs	Shape (oblique or perspective view)		Tour Eiffel, Notre Dame
		Shape (elevation)		Tour Eiffel, Notre Dame
	Typifying pictorial (realistic) signs	Shape (oblique view)		Sugar house, tourist hotel
		Shape (elevation)		Aluminium-works, oil refinery
	Typifying abstract (diagrammatic) signs	Shape (elevation)		Iron-works, coniferous tree
		Shape (outline)		Farmstead, coniferous tree
Area signs	Symbol screens and patterns	Shape (outline)		Orchard, park
		Shape (oblique view)		Forest, mountains
		Shape (elevation)		Mountains
	Coloured areas	Colour	Dark Green; Sienna	Coniferous forest, desert
Line signs	Line symbols	Shape		Railroad, road
		Colour	Blue; Grey	Canal, road

Fig. 7. Iconic function of signs: external similarity

– the monument of nature may be either iconic (green) or symbolic (red). In that group of signs shape is the most important iconic element.

Iconicity of sign shapes is graduated: their shapes range from individual pictures, i.e., the drawings of objects, to abstract point signs which depict typical traits of the outward appearance of the class of objects referred to by a sign.

Hue may also perform iconic function in area signs, e.g., the natural colours used on environmental maps to depict land cover (see Czerny 1983).

On the other hand, iconic function in symbol screens and area patterns is performed by shape.

In those examples iconic relationship holds as a rule between the sign type and the class of its denotata. The signs in the presented class, point signs in particular, are pictographs[4] which express definite concepts and thus constitute an ideographic alphabet.

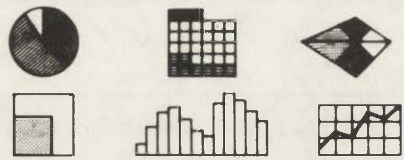
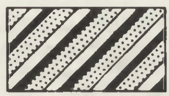
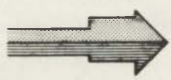
Kinds of signs	Examples of signs	Distinctive graphic element
Point signs (segmented symbols and cartograms)		Size (interrelationships)
Area signs (alternate band maps)		Size (interrelationships)
Line signs (flow-lines)		Size (interrelationships)

Fig. 8. Iconic function of signs: abstract similarity

Some cartographic signs which are dissimilar in the outward appearance from their denotata may have similar internal structure (fig. 8). Segmented point symbols and cartograms (line graphs, bar graphs, vector diagrams etc). belong to that class of signs. A simple choropleth map in which densities are represented by bands and subdivided graduated line symbols should be ranked with the same class as well. In such cases iconic function consists in transferring relationships, i.e., in creating abstract similarities. An area sign or a line sign has an additional element of configuration whereas a point sign does not have it. With respect to its graphic elements an area or line sign can be symbolic, but whenever such a sign is used on a map the iconic element, inherent in the configuration of each sign token, becomes apparent (fig. 9). Whereas on topographic maps outward similarity in the configuration of signs is preponderant, on thematic maps abstract similarity is dominant.

[4] "Pictograph" means "pictorial sign". Pictography or picture writing was on early development stage of the written language. As such signs are easily comprehensible and evoke mental associations with designated objects they are often used to provide information in tourism, transportation, etc.

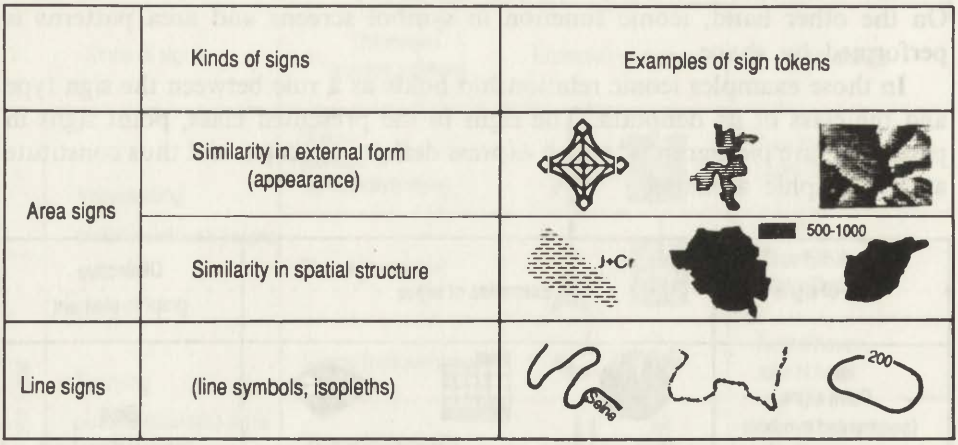


Fig. 9. Iconic function of signs: similar configurations

In semantic terms, map can be also regarded as sign. In the case of map with simple content iconic function of the sign used on it is manifested solely by the similarity of configuration of its constitutive elements on a plane (of point signs, line signs and area signs) to the spatial distribution of the phenomenon mapped (figures 10 a, c, e). In the case of map with a complex content, representing a classification, order or quantification, iconic function of the signs used on them is manifested by the similarity of different relationships, both spatial and non-spatial (figures 10 b, d, f).

To sum up, cartographic signs can be said to perform both symbolic and iconic functions. Iconicity of signs, interpreted as the similarity of their outward appearance as well as their structure, is the feature which differentiates cartographic model from models (descriptions) of reality built with the use of scientific symbolic languages. Just that feature endows cartographic model with graphicness which is not characteristic of symbolic models in a strict sense.

The colloquially used term "cartographic symbol" does not refer to the semantic feature of arbitrariness as not all map signs are arbitrary. The term "cartographic symbol" refers to the pragmatic feature of conventionality, characteristic of any signs used on maps.

2.3.4. PRAGMATIC RELATIONS

Sign understanding is a basic pragmatic relation. Adequate understanding, i.e., accurate interpretation of signs is based on some interpretation rules which associate those signs with their meanings. The knowledge of those rules is a necessary and sufficient condition which a map user must fulfil if he is to create and interpret a map consciously. Cognitive and communicative goals will be achieved by means of a map on the condition that the same set of interpretation rules is applied by all its users.

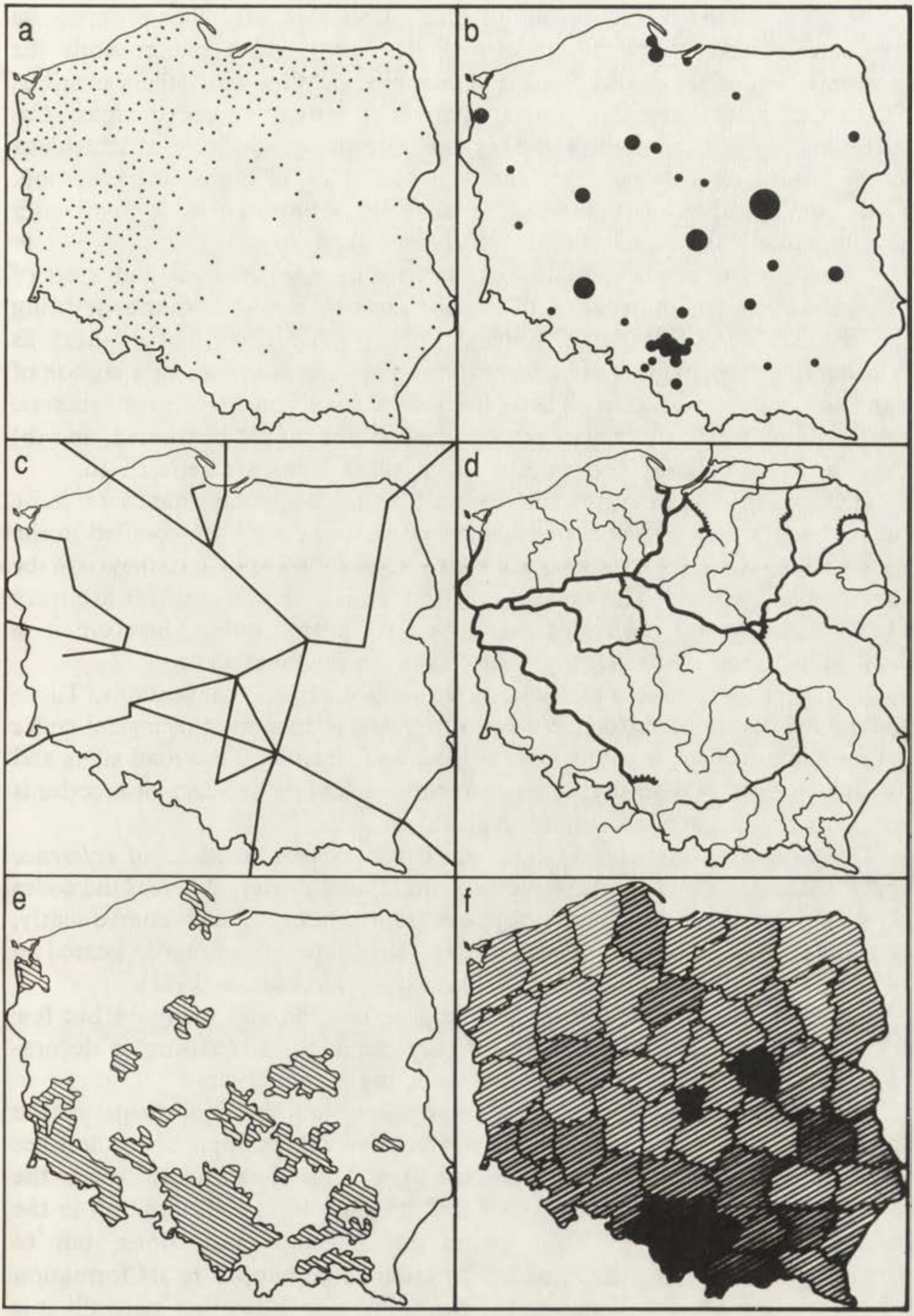


Fig. 10. Maps: similarity of spatial structure and internal structure

a – sugar beet production, b – industrial centres, c – air route network, d – waterways, e – industrial areas, f – density of population

Mapmaker maps reality in graphic substatum. In the process, he creates a system of cartographic signs (a code) which makes both the representation of the reality known and communication with others possible. Consequently, in pragmatic terms, map is a system of coded signs. *Codification*[5] should be interpreted as an agreement which is strict, binds all the users of a given map nad sets the rules of signs interpretation. That binding agreement cannot be changed arbitrarily by a map user as this would involve misreading of a given map.

The system of conventional signs, comprising a set of signs and a set of rules, is a *code*, communication of definite facts by means of that code being the relation constituting the system. Cartographic code, known also as "cartographic language" can be regarded as a system composed of a lexicon of signs and codification rules. The collection of rules consists of: (a) syntactic rules defining how correct cartographic expressions should be formed, and (b) semantic rules defining the objects which those signs are reffered to.

It is possible to interpret cartographic signs adequately thanks to some conventional rules: (1) semantic rules are explicit and they are codified in the legend of a map; (2) syntactic rules are used intuitively, but they can be identified and worded. The agreement which binds map users regards arbitrary signs (symbols) and motivated signs, i.e., the iconic ones. Therefore it is justified to term all the cartographic signs *conventional signs*.

In general, scientific and technical codes are explicit conventions. Those codes have the so-called *logical mode of reference*. Examples of logical codes are the symbols used in mathematics, logic and chemistry, the road signs and the flag alphabet. Generally, the agreement in scientific and technical codes is very strong, i.e., obligatory and explicit.

Quite different systems of signs which use *expressive modes of reference* apply to fine arts (as painting, sculpture, music) and poetry. Whereas the codes of logical type are geared to objective representation, and consequently, knowledge of a subject, the codes of expressive type are primarily geared to evoking subjective impression with the recipient (Guiraud 1971).

In principle, maps represent the first type of code and there are but few maps, the so-called pictorial maps, usually meant for advertising or decoration, which should rather be ranked with the second type.

Formation rules of cartographic expressions are the equivalents of the natural language syntax. Those rules are not explicit, as opposed to the rules establishing the meanings of cartographic signs. Map users usually keep to the formation rules not quite consciously and they use their own intuition in the process of map reading. This applies not to map users alone, but to mapmakers as well, at least in part. The latter often happen to set formation rules intuitively and not always to the point. Practice shows that generally it is enough for an experienced map reader to have the legend of a map containing

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[5] The concept of codification has been taken from semiotics (see Guiraud 1971).

a set of semantic rules to understand the content of the map properly. A mapmaker, however, should rather be fully aware of the formation rules he applies. The task of the semiology of graphics is to reconstruct the system of cartographic language general rules, both necessary and sufficient to form correct cartographic messages.

Syntactic rules can be formulated exhaustively only with reference to a specific map. The number of syntactic rules may vary from one map to another over a very wide range. It would be a very difficult task, however, to make a complete collection of rules governing construction of all the cartographic representations as a hypothetical set of rules of that kind would have to be extremely complex. That is why Bertin (1967) analyzed the general formations rules for cartographic representations by using the example of their simplest forms, the so-called images, to which any cartographic representation can be reduced.

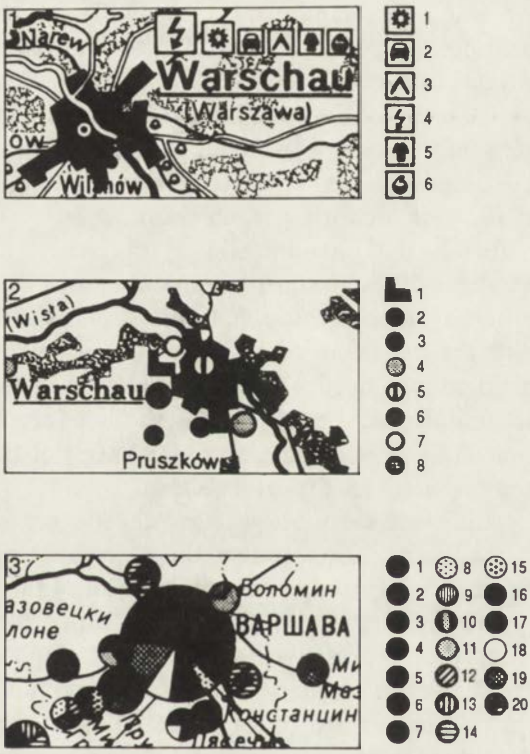

Fig. 11. Formation rules: examples

1. A portion of economic map (from *Alexander Weltatlas*, 1:3,000,000, enlarged), 1 – machinery, 2 – motor vehicles, 3 – precision instruments & optical goods, 4 – electronics, 5 – clothing, 6 – chemicals

2. A portion of economic map (from *Diercke Weltatlas*, 1:3,000,0000, enlarged), 1 – iron & steel, 2 – metal goods, 3 – vehicles, 4 – chemicals, 5 – electronics, 6 – textiles & clothing, 7 – precision instruments & optical goods, 8 – glass & pottery

3. A portion economic map (*Spravochnaya karta. Polsha*, 1:3,500,000, enlarged), 1 – iron & steel, 2 – metal & machinery, 3 – electronics, 4 – precision instruments, 5 – vehicles, 6 – motor cars, 7 – tractors & agricultural machinery, 8 – pharmaceutical goods, 9 – timber, 10 – paper, 11 – glass & pottery, 12 – textiles, 13 – cotton, 14 – flax, 15 – silk, 16 – clothing, 17 – footwear, 18 – food, 19 – miscellaneous, 20 – power-station

The questions of applying formation rules of cartographic expressions have been exemplified by three economic maps in figure 11. To know the legend of a map alone is not enough to know its code. This is because it is not known according to what rules the complex expression composed of the signs shown in the legend have been formed. On the first map (*Alexander Weltatlas*) signs are arranged below the name of the industrial centre; according to the rule adopted for the second map (*Diercke Weltatlas*) signs are located around the industrial centre; in the third case (the Russian map) range graded subdivided circles were formed. Conventional formation rules of cartographic expressions of the signs shown in the legend are reconstructed by a map user from the context, i.e., from the map itself.

Not all the formation rules are easy to read from the map. Whereas in the first case the linear arrangement of signs below the name of the city was unambiguous, in the second case, cartographic message seems to be liable to one of the two following interpretations: (1) the configuration of signs may be interpreted as corresponding to the real spatial distribution of industrial plants; (2) the configuration of signs may be interpreted as arbitrary and not reflecting the real spatial distribution of industrial plants. Only after referring to the supplementary information from other sources is it possible to state that the configuration of signs on the map in *Diercke Weltatlas* was arbitrary (except for the iconic sign denoting ironworks).

Pragmatically, this is the phenomenon of polysemy, i.e., ambiguity of cartographic expression. Although signs are unambiguous thanks to the legend of the map, unambiguity of cartographic expressions is not warranted. The message concerning the location of objects may involve more than one interpretation. This does not result from the polysemy of the code itself, but rather from the fact that syntactic rules are unwritten. Moreover, in the second case, the rules of placing signs on the map plane have not been so obvious as the codes of the maps used in the other cases.

The analysis of different cases shows that the degree of codification of cartographic signs may vary. The stronger the agreement between its user is (i.e., the degree of freedom left to them is minimum) and the broader it is (it is observed by a large number of people) the more codified the sign is. Extreme cases of such cartographic representations are photomaps, birds-eye views and pictorial maps. Thanks to iconicity of signs they can function independently of the agreement written in the form of a legend. This is because motivation of signs allows for their both intuitive and subjective interpretation. An agreement like this contains a collection of empirical rules of interpretation of signs which not been expressed exactly and which are usually applied unconsciously. In the case of such conjectural rules of interpretation the agreement which sets them may be called "tacit agreement" as opposed to "explicit agreement" in the form of the legend of a map.

The codification is the strictest in the case of topographic maps which usually make up a uniform, normalized system, covering the whole territory of the country. The precise agreement, established overhead in the form of map specifications contains the settlements which must be observed not only by the map readers but by the mapmakers as well.

Some codifications may be transnational. The international colour convention for geological mapping, adopted by the International Geological Congress in 1881, is probably the broadest agreement of the type. At the same time, that codification is not very strict as the national geological surveys have their local colour conventions based on said codification.

Cartographic signs can be codified on the basis of a broad agreement on the condition that an accepted classification of the universal set of map subjects is available. For instance, pedology does not have such a classification of research subjects (soils) which would be comparable to the stratigraphic division in geology. The FAO-UNESCO international classification is not used universally and some countries (Poland among them) use genetic typologies of soils.

As the division of topographic phenomena is self-evident, international codification of signs is easier to make with respect to the signs used on topographic maps than to the ones used on thematic maps.

Broad codification of signs is easier to make in official cartography than in commercial cartography in which graphic form of signs is characteristic of the individual style of each company. In those cases stylistic relationships, which belong in the category of pragmatic relations, are of great importance.

All those problems encountered by cartography contribute to the fact that signs used in that branch are not codified to such a degree as, for instance, in chemistry (chemical symbols) or in seamanship (signal code), the agreements binding in both the cases being strict and broad at the same time. In cartography there are four kinds of codifications, i.e., the agreements which define ways of interpreting signs:

(1) Codification in the strict sense, is an explicit agreement in the form of the legend which specifies the inventory of signs and establishes one-to-one correspondence between sign types and their meanings. Those written agreements are supplemented by unwritten, conventional rules governing formation of a map image, i.e., the rules of combining simple signs into appropriate structures.

(2) Codification in broad sense is also an agreement which standardizes more or less strongly and broadly the use of signs on particular types of maps: topographic, geological or tourist maps. Just as in the first case, the agreement is explicit, i.e., written.

(3) The third kind of codification is a common practice based on custom, such as, e.g., orienting maps to north, spectral progression of colours for relief maps or using italics for hydrographic features. These unwritten rules make up a codification in the form of a tacit agreement.

(4) The codification in the form of an unwritten agreement consists of the rules of signs interpretation for the users of cartographic representations which

have no legends and contain mainly iconic signs (pictorial maps, photomaps, brids-eye views, panoramas, block diagrams, etc.).

The above can be recapitulated by saying that codification, i.e., the agreement binding all the map users, rank among the relationships constituting the system "cartographic model". This codification establishes the assignment of definite meanings with each sign (semantics) and settles the rules of combining those signs to form complex cartographic expressions (syntax). Codification of cartographic signs is a necessary condition to adequate interpretation of all the messages read from a map[6].

2.3.5. SUMMING UP

As it follows from the above characteristics of semiotic relations, a cartographic model can be said to constitute a system which may be described by the following formula:

$$(M)S=[R(M)]P.$$

In that formula, P stands for the property of optimal performing the cognitive function. R stands for the structure of the system, i.e., the set of relations $R=\{R_1, \ldots, R_n\}$, which makes it possible to map the reality observed in graphic material. The following relations belong to the set R:

R_{I} – syntactic relations which make it possible to map the internal and spatial structure of the modelled fragment of reality. Especially three kinds of relationships: equivalence relations, ordering relations and quantitative relationships in the set of cartographic signs represent similar relationships among the mapped objects.

R_{II} – semantic relations between the elements of a map and the objects of the modelled reality, the iconic and symbolic relationships being ranked with that type of relations. Iconic signs and symbols are complementary: graphicness of cartographic model is conditioned by iconic signs and abstractness of the model depends on symbols.

R_{III} – pragmatic relation of codifying creates a cartographic language which is used in the construction of cartographic model and in communication.

M denotes elements of the system, i.e., the set of all the sign tokens on the map; the tokens which are identical and have the same meaning constitute subsets $M=\{T_1, \ldots, T_n\}$, called types.

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[6] In Schlichtmann's article (1979) the problem of cartographic codes has been viewed in a different way. The author explains cartographic communication by using the concept of code defined as the "set of descriptive rules which correlate marks with meanings". He distinguished several kinds of codes used in the process of cartographic communication: denotative codes which couple marks nad meanings directly; connotative codes which do so through intermediate meanings; general codes which comprise the common conventions of cartographic representation; special codes which specific knowledge of the mapped phenomena. For instance, general denotative code is used to transcribe basic topical and locational information.

2.4. MAPPING OF REALITY

2.4.1. ISOMORPHISM

It would be both impracticable and unnecessary to build a model which would be a complete representation of extremely complex real system. Therefore many non-essential properties and relationships characteristic of the system modelled are omitted. Thus, if system M is to be the model of system S, a subsystem M must be an image (model) of a subsystem S (fig. 12).

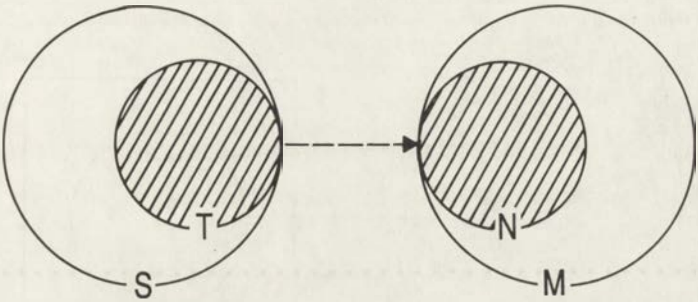

Fig. 12. Relationship between modelled system and model

Isomorphism, homomorphism and correspondence are the concepts of mathematical logic. They are used to formalize the colloquially used concept of analogy and describe the relationships between the model and the object modelled precisely.

Isomorphism can be defined for relational systems which have following form: $S = \langle A, R_1, \ldots, R_n \rangle$ where A stands for a set of elements, and $R_1, \ldots, R_n$ are the relations between members of the set A. These relations make up the structure of the relational system S (Kondakov 1983). Two relational systems, S and S' are isomorphic if and only if:

(1) There is a one-to-one function f which associates exactly one member of the set A' with each member of the set A. This means that each of the two sets has the same numbers of elements and that each element $a \in A$ is associated with one and only one image $a' \in A'$ and vice versa.

(2) Relation R holds between any members of the set A if and only if their counterparts in the set A' are associated by the similar relation R'.

Isomorphism represents identity of the system structure. Relational system S' is the isomorphic image (model) of the system S, and vice versa, as isomorphism is a symmetric relation. The relation of isomorphism is rather common. For instance, similarity is an isomorphic transformation of a figure into another figure. Map projection transforms the spherical surface to a plane in such a way that one-to-one correspondence between the points of the original nad the image is established. Moreover, a definite complex of geometric relationships in the image, depending on the properties of a given projection, agrees with the original. Map projection, for instance, represents the so-called partial isomorphism which has reference to selected relationships only.

The relationships between a negative and its enlargements, and the relationships between a worksheet, a fair draught and a ready map can be quoted as informal examples of isomorphism. In those cases different types of relationships, not only geometrical ones, are isomorphic.

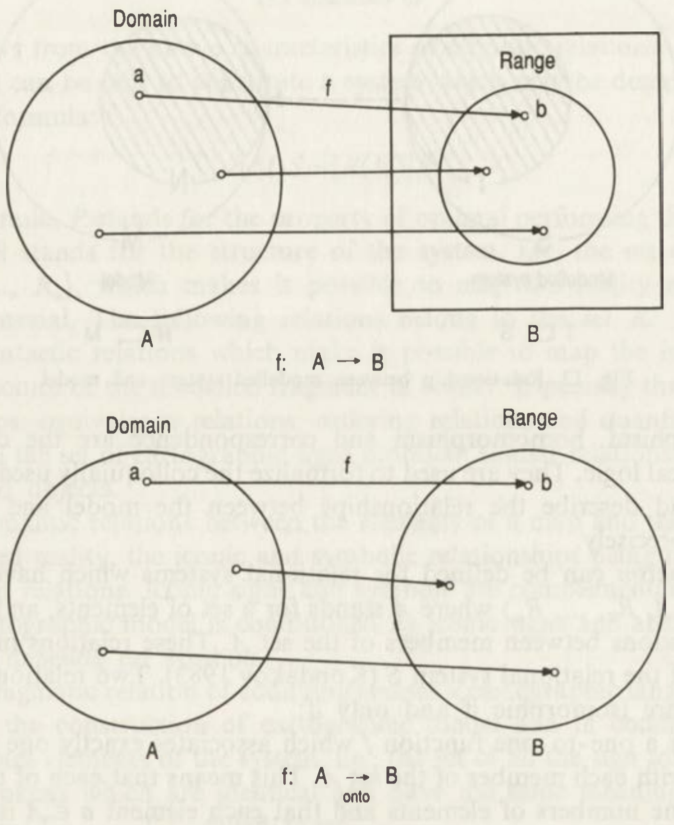

Fig. 13. Mapping

Now the concept of *mapping* (in the sense of set theory) will be presented. Mapping of set *A* into set *B* is a many-to-one relation (function) which assigns to every member of the set *A* a unique element of the set *B*. Figure 13 clarifies the concept defined above. The expression f: $A \rightarrow B$ reads: function *f* maps the set *A* into the set *B*. If the range of function *f* is equal to the set *B*, i.e., if all members of *B* are associated with members of *A*, then it says that *f* maps the set *A* onto the set $B(f\colon A \underset{onto}{\rightarrow} B)$ (Kondakov 1983).

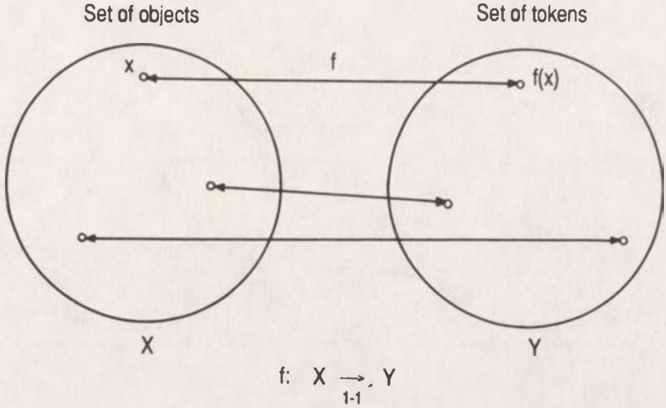

Fig. 14. Association of sign tokens with objects

Let us consider first association of sign tokens with individual objects (fig. 14). Let X stand for a set of objects, Y – for a set of sign tokens on the map, and $f(x)$ – for a token assigned by the function f to the object $x \in X$. Function f is one-to-one mapping of the set X onto the set Y. This makes it possible for the map reader to identify any token with a definite individual object, and vice versa.

Fig. 15. Domestic air routes (map)

The question to answer now is whether mapping f is or is not isomorphic. Isomorphic mapping is reversible, i.e., all the elements and relations of the original can be reproduced from their image (model). It is not possible to reproduce either objects mapped or spatial relationships between them from

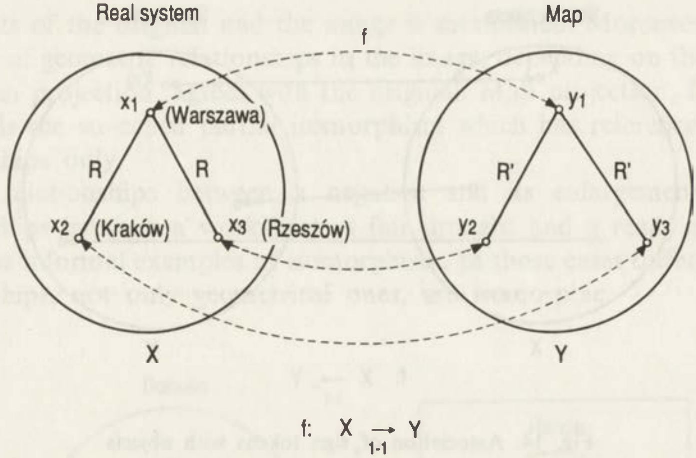

Fig. 16. Mapping of domestic air routes

the cartographic model without simplifying them as a result of cartographic generalization. This implies that map is not an isomorphic model. Idealization, however, makes it possible to regard a plan (a large-scale map) as geometrically similar, i.e., isomorphic image of a countryside. Also, graticule on the surface of a map can be regarded as the isomorphic image of the graticule on the surface of the Earth.

In cartography, not only spatial relationships can be mapped, but many other kinds of relationships between objects as well, the structure of the real system mapped being simplified due to generalization. And yet, exceptional cases of isomorphic mapping of the real systems can be quoted. An example is a map of domestic air routes in Poland (fig. 15). The map is an isomorphic

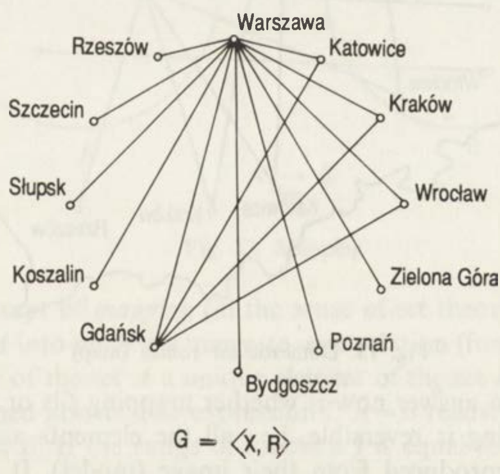

Fig. 17. Domestic air routes (graph)

model of a simple relational system: $S = \langle X, R \rangle$, where X is the set of the Polish cities with airports, and R is a direct air connection relationship. Figure 16 shows the relationship between the relational system in question and its cartographic model. To simplify the diagram, only selected points and lines, representing the elements of the system and the relationships between them have been plotted.

R' denotes the relation between a pair of sign tokens connected on the map with a line. It is evident that the condition that individual objects, being the elements of the set X, are connected by the relation R if and only if their images (the elements of cartographic model) $y \in Y$ are connected by the relation R' has been satisfied. Of course, no mention has been made of spatial relationships. The representation of spatial relationships is simplified and for that reason neither the boundaries of Poland nor the location of the airports can be reproduced in the countryside on the basis of the map accurately. Also graph G (fig. 17) is an isomorphic model of the relational system $S = \langle X, R \rangle$. In this case the relation of isomorphism holds between the real system, the map and the graph.

2.4.2. HOMOMORPHISM

Strong homomorphism is the generalization of the concept of isomorphism defined as follows (Kondakov 1983):
Relational system S' is a homomorphic image of the system S if and only if:
(1) There is a function f which assigns to each member of the set A exactly one member of the set A' (but not vice versa as more than one member of the set A may be associated with one member $a' \in A'$);
(2) Relation R holds between any members of the set A if and only if a similar relation R' holds between their counterparts in the set A'.

A more general concept of *homomorphism* has been put forward (Kondakov 1983). The definition is similar, but whereas the first condition remains unchanged, i.e., the function f is not one-to-one mapping, the second condition should be replaced by the following condition:
(2') If relation R holds between any members of the set A, a similar relation R' holds between their counterparts in the set A' (but not vice versa).

Relational system S' is called a homomorphic image, or a homomorphic model of S. Unlike isomorphism, homomorphism allows for simplification of the system mapped, so consequently, it is not a symmetric relation. Strong homomorphism and isomorphism are special cases of homomorphism.

Maps represent spatial phenomena occurring above and below the Earth's surface (e.g., geological maps, marine charts, weather charts). All the elements of lithosphere, hydrosphere and atmosphere can be the subjects of cartographic modelling. Thus, the scope of cartographic modelling encompasses three-dimensional space.

While the projection of the spherical Earth's surface (or ellipsoid) onto a plane is an isomorphic mapping, the projection of the set of points of

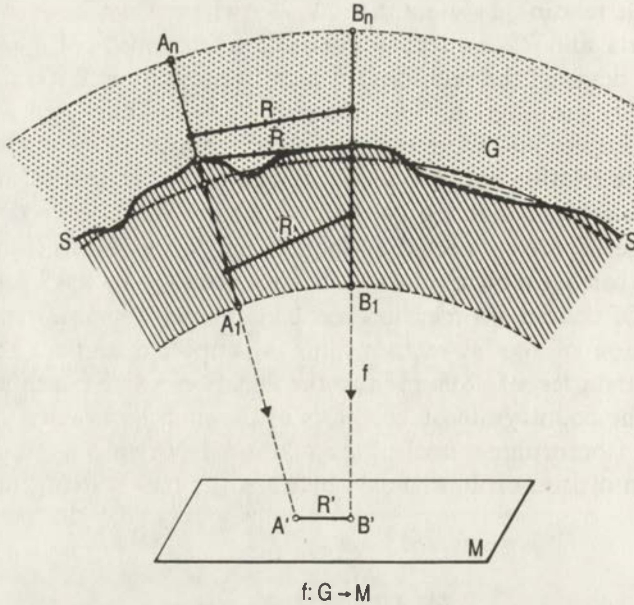

Fig. 18. Mapping of the geographical sphere into a plane
G – set of points in the geographical sphere, *M* – set of points in a map plane, *SS* – the earth's surface

three-dimensional space onto the plane of the map is not isomorphism (fig. 18). Each point in space is associated with exactly one image, i.e., with a point on the plane, and simultaneously, each point on the plane of the map is associated with a set of points situated on a vertical line. Thus, the function which establishes the association of points is not a one-to-one function, but many-to-one function. Moreover, spatial relationships are mapped onto geometrical relationships on the plane of the map in such a way that the relation *R'* between the images of points holds if and only if the relation *R* holds between those points. From this it follows that strong homomorphism occurs. A strongly homomorphic model is an incomplete image of the original's structure, e.g., it fails to show spatial relationships in the set of points in space, as the set of those points is associated with any point on a plane.

The mapping of the real system, if considered with respect to non-spatial relationships, is not a one-to-one mapping either, hence, it is not isomorphic. If symbolization, i.e., the association of sign tokens with objects according to the properties of those objects is considered, the analogy between symbolization in cartography and measurement is clear. As is known, the measurement procedure associates unique numerical values with objects, e.g., the same numerical values are always associated with congruent line segments as the measures of their length. Measurement function maps the relationships between objects onto the relations between numerical values, the condition of strong homomorphism being satisfied by that mapping.

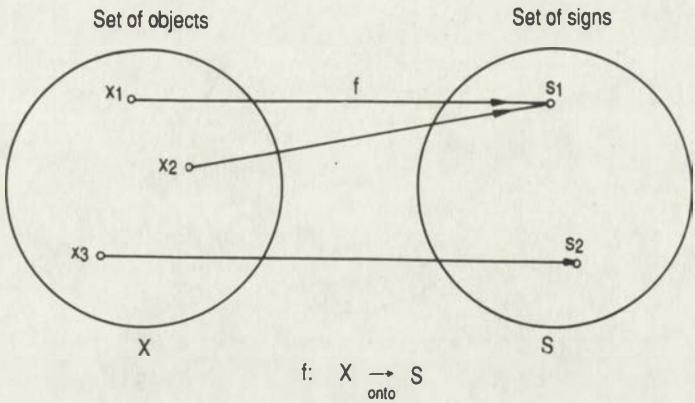

Fig. 19. Association of sign types with objects

While drawing a map a mapmaker associates a unique cartographic sign with an object (fig. 19). This association is a function. If function *f* is such that to the objects which have a property in common always the same sign is assigned, and to the objects which do not have any such property different symbols are assigned, and moreover, if from certain relationships between signs conclusion can be drawn that similar relationships hold between objects, then the mapping satisfies the condition of strong homomorphism. This statement can be exemplified as follows:

I. With respect to the nominal features the conclusions which can be drawn from the map may concern only similarity or dissimilarity of objects:
(a) a set of topographic objects is split up into classes of similar objects (e.g. churches, monuments, foresters' houses, etc.), then a symbol of different shape is assigned to each class of objects;
(b) the equivalence relation "the same tree species" classes forests into pine, spruce, beech, etc., the tree stands belonging in the same equivalence class being symbolized on the forest map by the same colour.

II. Mapping ordering features make it possible to infer about ranking of the objects mapped, e.g., the relationship "higher administrative rank" partially orders the set of Polish cities ⟨{the state capital}, {voivodship cities}, {other cities}⟩. Various kinds of signs (e.g., point symbols, letterings or underlinings) can be used to represent the ordered set of cities on the administrative map. The visual weight of signs of each kind should be differentiated in order to portray three classes of the cities.

III. As far as quantitative characteristics are concerned, signs can be assigned to objects according to the rule which will make it possible to draw much broader conclusions concerning the relationships between those objects. Signs can be assigned to the quantitative characteristics of objects so that inferences can be made from relationships between the sizes the signs on relationships such as ratio and/or difference between quantities being mapped.

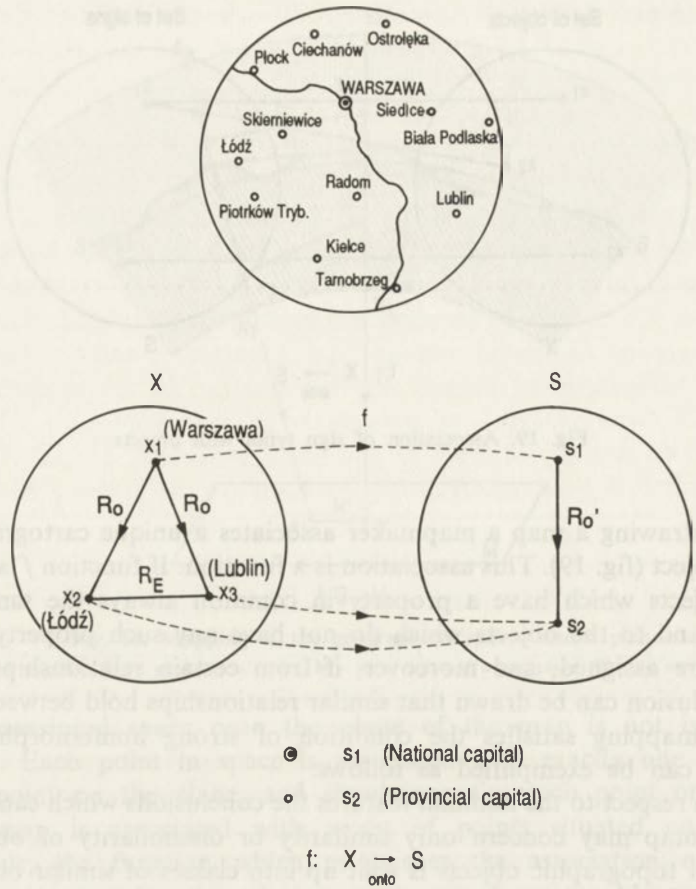

Fig. 20. Mapping of the relation which partially orders a set of cities

For instance, graduated symbols are assigned to towns, the areas of those symbols being proportional to the respective population numbers.

The following graph (fig. 20) exemplifies case II: R_0 denotes the relation which partially orders the set of towns, and R_E stands for the equivalence relation "the same administrative rank". The relation R_0', ordering the set of cartographic symbols on the map, agrees with the relation R_0, and the identity relationship in the set of symbols corresponds to the equivalence relation R_E as identical symbols have been assigned to two towns of the same rank. That relation can be conceived as a loop with the beginning s_2 and the end s_2 (not shown in fig. 20 for the sake of simplicity). The condition that the relations must agree in both directions: reality – map and map – reality is satisfied. As a definite relationship holds on the map, it is logical to conclude that a similar relationship holds in reality.

The same applies to the mapping of the equivalence relation which establishes the classification of the set of mapped objects (case I) and for the mapping of binary operations of the type $o(x, y) = z$ which are transferred from the real system to the map (case III).

In all those cases signs are associated with the properties of objects by one-to-one mapping. On the other hand, signs are associated with objects by many-to-one relations. The mapping of the relations between properties onto the set of relations between the signs is isomorphic, and at the same time, the mapping of the relationships between objects is strongly homomorphic.

2.4.3. GENERALIZED CONCEPT OF MAPPING

Should the second condition formulated in the definition of strong homomorphism be weakened so that the agreement of the relations is in one direction only, i.e., original – image or image – original, more general kinds of mapping would be obtained, i.e., homomorphism and correspondence. *Correspondence* occurs if the function f which transforms the set A into the set A', satisfies the following condition (Shreyder 1971): (2″) If relation R' holds between any members of the set A', then similar relation holds between their counterparts in the set A (but not vice versa).

Roughly speaking, the cause of each relationship between the elements of the model lies in the relationships between the elements of the system modelled. According to the above definition, homomorphism which is also correspondence is called strong homomorphism.

Let us consider positional relationships of objects. In normal Mercator's projection the relationship "is located east of" is mapped onto the relationship "is located right of", and the relationship "is located north of" is mapped onto the relationship "is located above". On the small-scale Mercators' map, the symbols representing the towns of Minneapolis, Turino, Belgrade and Kzyl-Orda are located on the horizontal line showing the parallel of latitude at 45°N. The differences between the latitudes of Kzyl-Orda (44°48′N), Belgrade (44°50′N), Minneapolis (44°59′N), and Turino (45°03′N) are not shown.

Thus, it is evident that even if some objects are connected by ordering relation "x is located north of y", it does not always mean that the signs representing those objects are connected by a similar relation. On the other hand, from the relationship "x is located obove y" on the plane of the map it can always be inferred that a similar relationship holds between objects mapped. Consequently, from the fact that the sign of Cracow is located above the sign of Belgrade it can be inferred that Cracow is located north of Belgrade. A similar inference can be made with respect to any pair of towns.

The situation is different with the equivalence relation "the latitude of x is the same as the latitude of y" which is always transferred from reality onto the map, and not vice versa.

The mapping of positional relationships of objects does not satisfy conditions of strong homomorphism. Those conditions cannot be satisfied as the elements of the map, are not dimensionless points but signs. In specific cases the relationship may be either correspondence or homomorphism.

All the sign tokens have a definite location on the map: $(Y_1)L_1, ..., (Y_n)L_n$. The association of tokens with objects can be considered on semantic level (content plane), i.e., with respect to the tokens' role of representing the locations of objects. This is a many-to-one mapping as the set of tokens $(Y_1, ..., Y_n)L$ may be associated with a single location. The set of tokens composes a *syntactic unit*; all the sign tokens are ordered in some way, e.g., their arrangement is linear and all of them refer to the same location. The most common reference point is the location of the symbol of a town on the map (fig. 21). In that case, the syntactic rule applies which permits to depart from

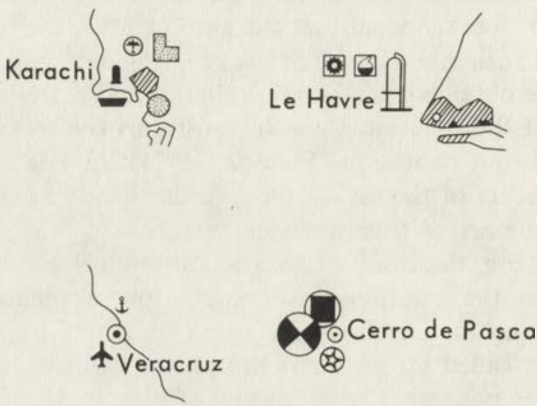

Fig. 21. Undistinguishableness of locations

locating the sign tokens in their proper positions according to the map projection system. As the illustration makes it clear, the locations of the signified objects "merge", i.e., the relationship of indistinctness holds among some objects with respect to their location on the map. Line signs or area sings may also compose syntactic units in case two or more sign tokens refer to the same position.

Taking draughting accuracy and the scale of the map into consideration, it can be said that each point on a map actually corresponds to some real area. For instance, a dot with the diameter of 0.4 mm denoting a spot height on a continent map at the scale of 1:40,000,000 corresponds to the area of nearly 200 km^2. Spatial relationships occurring in that area cannot be represented on the map plane.

Strong homomorphism implies an indistinguishableness of only those elements which have some property in common, whereas mapping of spatial relationships admits of indistinguishableness ("merging") of the properties of the objects as well. Thus, for instance, the width of watercourses under 60 meters wide cannot be measured on the topographic map of Poland at the scale of 1:100,000 as the legend of that map specifies a class of watercourses up to 10 m wide (symbolized with a single line), and a class of watercourses

10–60 m wide (symbolized with two parallel lines 0.3 mm apart). The rivers which have more than 40 m in width are shown true to scale of the map, but the differences in width of fewer than 10 m could not be shown as the coastline is represented by the line 0.1 mm wide.

As it can be seen, the agreement in the mapping of spatial relationships can be in one direction only: either map – reality or reality – map. That mapping satisfies both the condition of correspondence and the condition of homomorphism for any relationship. This kind of mapping is not reversible, i.e., spatial structure of the system modelled cannot be reproduced from the model without simplification.

The simplification involved by mapping of spatial relationships corresponds to the concept of "form generalization" (see Ratajski 1973b). Now, it is possible to give a more precise characteristics of form generalization, i.e., a reduction of map scale which is accompanied by reduction of the magnitude of information about spatial relationships, whereas some specific relationships are retained. Namely, the configuration of sign tokens on a map has the following characteristics: (a) unique association of the locations of tokens with the locations of objects; (b) the agreement of locational relationships is in one direction only: map – reality or reality – map.

Now let us consider mapping of the remaining, i.e., non-spatial relationships. It is common in mapmaking to group the properties of mapped objects. The procedure consists in uniting (summing) the subsets of objects which have some properties in common:

$$\overbrace{X_1, X_2, X_3}^{\text{I}}, \overbrace{X_4, X_5, \ldots, X_n}^{\text{II}}$$

Each object belonging to the same class, obtained as a result of summing subsets $X_1, \ldots, X_i$, is associated with the same sign, whereas members of different classes are associated with different signs. As a result, such phrases as: "clays, sands and gravels", "meadows and pastures" or "textile and garment industry" appear in the legends. Grouping of the properties of objects usually involves creation of the so-called generic (superordinate) concepts, such as: "grasslands", comprising both meadows and pastures. Typical examples of such concepts are: "deciduous forests", "coniferous forests", and "mixed forests" or language branches, e.g., Slavonic, Italic, Germanic. Cartographers often employ graded partitions, that is, classifications used in various branches of science. For instance, legends of geological maps are always based on stratigraphic division of rocks into groups, systems, series and formations.

In the case of quantitative methods of cartographic representation, i.e., graduated symbols, choroplethic method and isaritmic mapping the properties of objects are grouped in order to establish class intervals.

The type of mapping in which the properties of mapped objects "merge" does not satisfy the definitional conditions of strong homomorphism. Figure 22 shows the map in which symbols representing towns are range-graded to

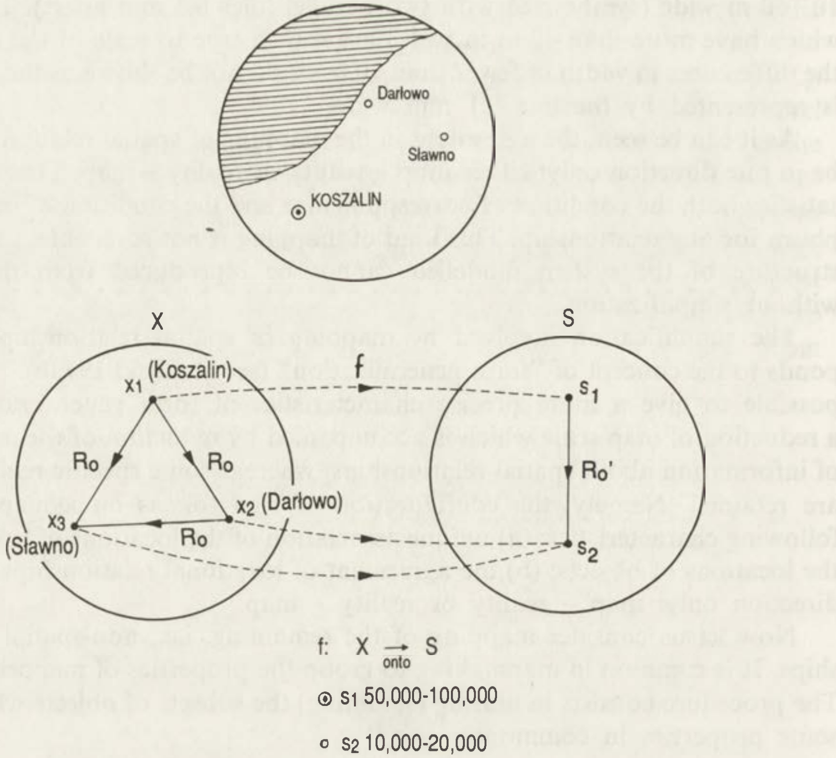

Fig. 22. Mapping of the relation which linearly orders a set of cities

denote population number. R_0 stands for the relation "greater" which orders the set of towns, and R_0' denotes the relation ordering the set of sign types. As the graph shows, whenever any two tokens are connected by the relation R_5', objects signified are connected by the relation R_0. The existence of the relation R_0 does not always imply that a similar relation R_0' holds on the map, as in some cases the same sign has been associated with the objects related by the R_0. As the relation R_0' corresponds to the relation R_0, the function establishing the mapping of the relations is correspondence.

Drawing of a hypsometric map involves mapping of the relation of higher elevation above sea level onto the relation ordering the set of colours used on the map, and the function establishing the mapping is correspondence as well (fig. 23).

The relation partially ordering a given set of objects does not always establish which of the two objects has precedence. This is because objects may be related by ordering relation "x precedes y" (which can be written as: $x>y$) or equivalence relation ($x \approx y$) which is a complement[7] of the relation $x>y$.

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[7] The relation $\bar{R}$ which holds between two objects if and only if the relation R does not hold between them, is called the complement of the relation R.

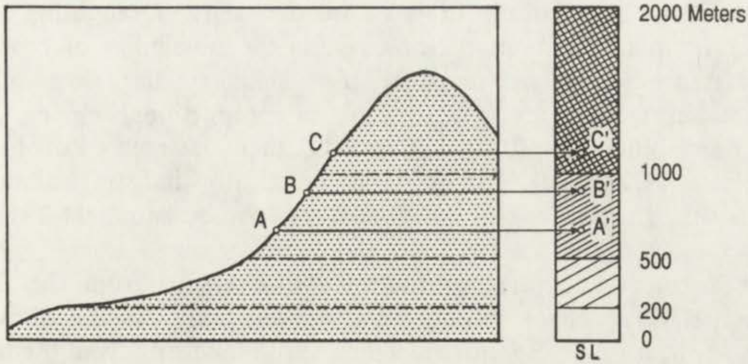

Fig. 23. Mapping of surface elevation

The fact that two objects are designated by the same sign type does not imply that the equivalence relation holds between those objects (fig. 20). If, however, two towns have the same population numbers, then identical signs are always used to designate them. As it follows from the above, grouping of the properties of mapped objects is connected with the homomorphic mapping of the equivalence relations between objects onto identity relations between signs.

The same can be said about the mapping of the set of objects whose partition is established by the equivalence relation between those objects. Figure 24 shows

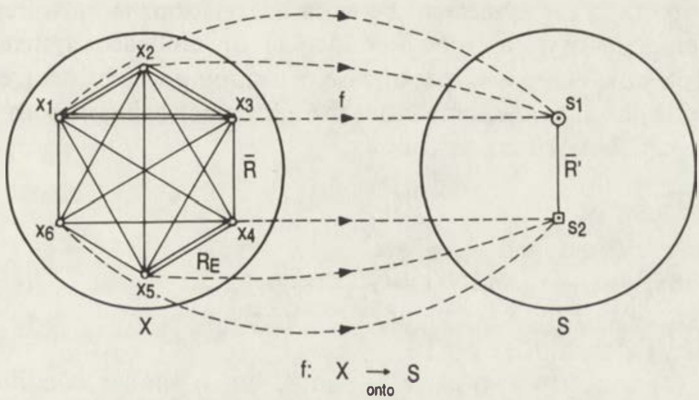

Fig. 24. Mapping of equivalence relation

the set of objects X whose partition is established by the relation R_E. Symbol $\bar{R}$ stands for its complement, that is the relation between the objects which are members of different subsets. The mapping of equivalence relation is homomorphism, and its complement $\bar{R}$ is correspondence as the fact that $s_1 \neq s_2$ always implies that designated objects are different (properties possessed by the objects vary).

The proportionally scaled graduated symbols quoted above as the example of strong homomorphism, should indeed be considered as the case of mapping which transfers the relations in one direction only. Draughting accuracy of the map, equalling about 0.2 mm, limits the possibility of representing ratio information on the map. If, for instance, the sizes of Polish towns are represented by the method of proportional circles, so that 1 mm^2 corresponds to 1,000 inhabitants, then Jastrzębie-Zdrój (98,500) and Zielona Góra (101,100) will be practically indistinguishable with respect to their sizes as the diameters of circles equal 11.2 and 11.3 mm respectively.

What is essential is the information which results from the fact that a definite relation occurs among sings on the map. As the above given examples show, it is correspondence which allows inferring from the map that such relations as "x precedes y" or "x is different from y" hold. On the other hand, it is possible to make logical inferences infallibly about holding the equivalence relations among objects on the necessary condition that strong homomorphism occurs. Theoretically, that condition can be satisfied only by a continuous value scale, thus, cartographic methods based on range-graded value scale do not satisfy it.

In conclusion: the system "map" may be regarded as a model of some real system because a definite connection between those systems makes it possible to infer from the data pertaining to the map about the modelled system. This means that there is such a mapping which satisfies the following conditions: (1) uniqueness of association of elements of the model with the elements of the mapped system; (2) the agreement between the relations in one direction only: model – modelled system (correspondence) or modelled system – model (homomorphism). There is a special case of mapping which is correspondence and homomorphism at the same time, the agreement being in both directions. The above can be written as follows:

(1) $f\colon A \xrightarrow[\text{onto}]{} A'$

(2) for any $x, y \in A$ and $x', y' \in A'$
such that $f(x)=x'$ and $f(y)=y'$ always
if $R'(x', y')$, then $R(x, y)$ or
if $R(x, y)$, then $R'(x', y')$.

Condition (2) concerns two-place relations, but a similar condition can be applied to the properties designated by one-place predicates $P(x)$, and for n-place relations $R(x_1, \ldots, x_n)$.

The conditions of the definition quoted above are satisfied by: 1° the mapping of a set of objects onto a set of sign types; 2° the mapping of a set of objects onto a set of syntactic units (i.e., of individual sign tokens or subsets of tokens associated with the same location on the map plane). In the first case, the relationships established on the set of sign types are the image of different relationships between objects; in the second case, the relationships on the map plane, established in the set of syntactic units, will present the image of positional relationships in the set of real objects.

Just those connections between the real system and its cartographic model make it possible to infer from the data pertaining to the model what relationships hold among the objects mapped.

The intuitive notion of the association between a map and the mapped fragment of reality is largely congruent with the concept of correspondence. This implies that any information obtained from a map can be transposed on the reality, but not everything that pertains to the mapped reality is actually represented on the map. Otherwise: holding of a relation *R* between objects is a sufficient condition to holding of a similar relation *R'* between their signs. If some relationships on the map are found not to agree with reality, then the map can be called not faithful.

If, however, it is required that definite relations holding between objects implicate similar relations on the map, then homomorphism of the mapping is assumed. To put it differently: holding of a relation *R* between objects is a necessary condition to holding of a relation *R'* between their signs.

As it follows from the foregoing examples, in some cases the mapping of reality may at least approximately fulfil the conditions of strong homomorphism. Only in exceptional cases can the relations on the map be regarded as a isomorphic image of the relations between mapped objects. The requirement of isomorphism in mapmaking turns out to be too stringent and not only useless but impracticable as well. The statement occasionally found in cartographic writings that a map is an isomorphic model is tantamount to the statement that the map is not generalized and strictly speaking both the form generalization and the quality generalization are lacking.

3. COGNITIVE FUNCTION OF MAP

3.1. INTRODUCTORY REMARKS

Once it has been assumed that map is the model of reality, it should also be accepted that the cognitive function of map is primary and essential. The representatives of the cognitive research orientation – Aslanikashvili, Salichtchev, Berlyant, Ogrissek emphasize consistently that a map is the means by which new knowledge of reality is gained. They believe that adherents of communication approach underplay the role of map in cognition, and that according to the existing theoretical models of cartographic communication the messages conveyed via the map do not contain any new information.

According to Aslanikashvili (1974), the cognition of reality by means of maps involves cognitive functions, comparison analysis and synthesis, abstraction (as regards spatial relationships) and generalisation (with regard to map content). In the process of mapmaking in which methods of induction, deduction, interpolation and extrapolation are employed some new knowledge of the spatial structure of mapped phenomenon is always gained. The information which cartographic model contains is absorbed from it directly. The information can also be obtained from the map indirectly through "logical processing" of the information gained directly.

This concept has greatly influenced the concept of the cartographic method of cognition proposed by Salichtchev (1976) who believed that new knowledge is the product of: (a) processing of the information on mapped reality at the mapmaking and map reading stages, the latter being accompanied by the visual, cartometric, graphic or mathematical analysis of cartographic information; (b) drawing of conclusions on mapped reality both from the data of the map and from the researcher's own knowledge.

Berlyant (1979) uses the concept of "map image", i.e., a spatial combination of signs to explain how new information comes into existence. According to him, that happens when some combinations of signs that constitute a cartographic representation of reality are reflected in the receiver's mind.

According to Grygorenko (1975), the information that can be read from the map consists of two categories of information: the one which is ready (explicit) and the one which is hidden and can be revealed by means of interpreting the map content.

Salichtchev's conception inspired Ratajski (1977) to supplement the conception of cartographic communication with the concept of "gains of information". Ratajski has distinguished open information and potential, hidden information which may become the source of gains of information. They accrue in the mapmaking process (data manipulation, generalization and symbolization) as well as in the process of map reading when interpretation of a map occurs. At the stage of direct obtaining of information locational relationships between objects are read, at the stage of obtaining information indirectly – associations between objects are read, and at the stage of obtaining derived information the analyses conducive to constructing of new maps are made.

Both the concept of new knowledge and the concept of gains of information relate to the information stored on the map. This approach leads to differentiating between two kinds of cartographic information, i.e., the information coded on the map explicitly which is interpreted by the map reader with the assistance of the legend, and the possible, hidden information which can be retrieved if map user applies additional knowledge and skills. The distinction of hidden information from open information, however, is dubious. It is questionable to confine the concept of open information to the information associated with individual signs, whereas the information associated with combinations of signs is regarded as hidden information. As is known, "maps for seeing" (cf. Bertin 1967) allow of recognizing and comprehending mapped spatial structures spontaneously.

In the later part of this work the process of acquiring new knowledge from map will be viewed somewhat differently. A significant feature of that approach consists in the fact that the concept of *new information* is related to the knower's knowledge. Consequently the information is new if map user's knowledge of reality has been supplemented with this information. This should make it possible to conceive of producing cognitive information by means of a cartographic model of reality in a different way.

In this Chapter the following concepts pertaining to information will be used (Pabis 1985):

Information is comprehending of meaning of the signals received, i.e., learning of some states of affairs from the signals referring to those states.
Cognitive information is gained by the knower in the process of cognition of reality and that information supplements his stock of knowledge.
Cognitive value of information is the property which can be evaluated subjectively. The information gained can be assessed as valuable only if it is properly comprehended, new and useful to its recipient who may pursue either some research purpose or a practical goal.
Knowledge is a set of information about reality, stored in the knower's memory.

3.2. THE PROCESS OF MAPMAKING

The first stage in cognition of reality by means of a map consists in cartographic modelling of that reality. The model is a result of the process of information collection, manipulation and transformation. A map may be either the result of empirical research or the use of existing models of reality. The former category of maps employ field mapping methods, the latter category, i.e., derived maps use compilation techniques.

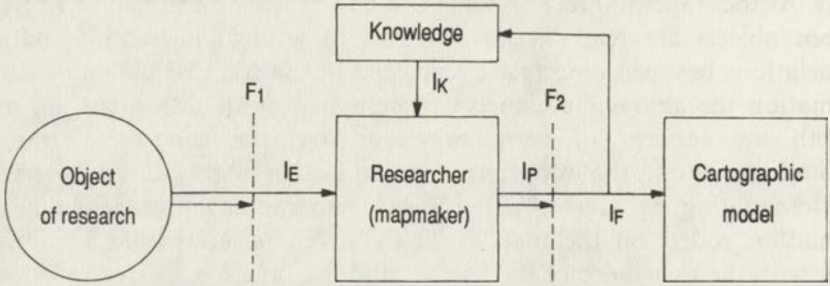

Fig. 25. Mapmaking based on empirical observations

I_E – empirical information, I_K – information used to elaborate and process I_E, I_P – information obtained by elaborating and processing I_E, I_F – final information set, F_1, F_2 – filters which cause the loss of information

The schematic diagrams presented below, inspired by the general models of the research procedure in empirical sciences (Pabis 1985), clearly illustrate how cognitive information conducive to the construction of cartographic model is produced. The first schematic diagram (fig. 25) shows how map is made in the process of the empirical research of reality. Let us assume that the researched and modelled object is the segment of reality which can be regarded as a relational system denominated "empirical system" by the methodology of empirical sciences. It should also be explained that a conventionally used term "researcher" denotes a specialist in a given discipline (e.g., a topographer, a geologist) or a team whose members are equipped with the necessary measuring instruments. The researcher has specialistic *knowledge*, comprising some information about the objects of research, the methods of research and manipulation of the data obtained as well as the knowledge of cartographic methods.

As a result of the *empirical research*, i.e., *observation* and *measurement*, the researcher gains new information which is valuable in respect of the purpose of his study I_E. Not all the available information is obtained, but only a subset if the researcher's knowledge happens to be insufficient, measuring instruments imperfect, if some accidental events occur or other unfavourable factors operate. The reduction in the quantity of information is symbolized by filter F_1. While manipulating the empirically obtained information the researcher makes use of his specialistic knowledge by selecting the information he actually needs I_K. If a mapmaker does make use of the whole set of valuable information I_P gained in the process of manipulating the empirically obtained information a loss, symbolized by filter F_2, occurs. This may result both from his incompetence and the inefficiency of mapmaking, including its compilation, fair draughting and reproduction. The schematic diagram also shows that the final set of information I_F, produced in the process of mapping and expressed in the form of a model, is used by the researcher himself and added to the knowledge he already had.

The empirical information expressed in the form of cartographic model by means of the code of graphic signs within a definite coordinate system on a plane is called in general "cartographic information". This notion, however, arouses controversies with reference to some specific issues (cf. Martinek 1973, *Multilingual Dictionary of Technical Terms in Cartography* 1973, Berlyant 1978, Pravda 1980, Vasmut 1983, Gołaski 1984).

The simplest case of mapping consists in recording new facts acquired in the course of empirical research (field mapping). In that case, manipulating of information is confined to *symbolization*, i.e., to the procedure which involves selecting of an appropriate code of graphic signs and coding of information. As a result, formally new information is obtained. In most cases, the information which has been partly processed is being symbolized. The researcher classifies or orders facts observed by resorting to his specialistic knowledge. There remains a question, however, to what extent a map is the record of "pure" perception and to what extent its elements are the results of interpretation.

In general, it can be said that the procedures involved in manipulating of the empirical information may contribute, depending on what is required, either to amplification or simplifying of the original information. A typical example of amplification of the information is the construction of a continuous image of a phenomenon from the data referring to selected measurement points (climatic maps). An example of simplification of information may be the selection of some control points (spot heights on general maps) which applies whenever mapping of all the points cannot be made.

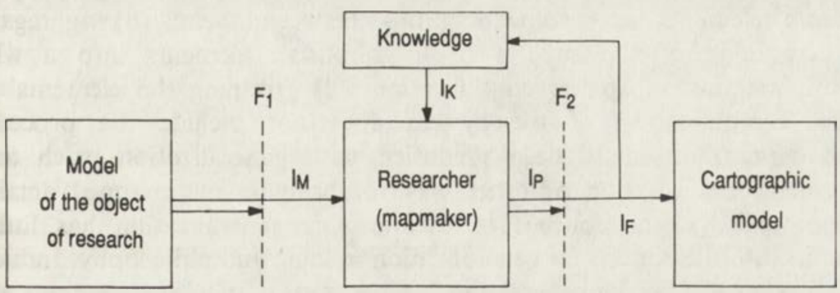

Fig. 26. Making of a derived map

I_M – information obtained by research of a primary model, I_P – information obtained by elaborating and processing I_M. Other symbols are explained on the fig. 25

Instead of knowing reality directly existing models of reality may be studied instead (cartographic models, remote sensing models, statistical models, descriptive models, etc.) to prepare a derived map (fig. 26). In the diagram the symbol I_M stands for the information that a mapmaker derived from the model of an empirical system on the system itself. The simplest case of manipulating source information may consist in the transformation of one code into another. This implies that formally new information has been produced. Constructing of a new map on the basis of statistical data, with the use of such code of map signs which ensures the smallest information loss (proportionally scaled graduated symbols) may be an example. The transformation of the source information content is also involved in most cases of mapping.

So far, the problem of processing the information necessary for map construction has not been discussed as a whole in cartographic literature. The attempts made in this field have been confined to *cartographic generalization* which includes only a part of procedures involved in handling of the source information (Ratajski 1973a, 1973b, Robinson et al. 1984, Hake 1982). The existing literature presents generalization as a specific cartographic method consisting essentially in the reduction of information. The method includes a set of operations conducive to the transformation of source information into a smaller set of data, processed according to the information capacity of map and to the purpose for which the map is being made. The essential properties of the mapped reality and the relationships within it are portrayed as a result of the transformation.

The concept of simplification of mapped system, implicit in Uyemov's definition (2.1), can be proposed as the explication of generalization concept. *Simplification* is such a transformation through which the complexity of the system can be reduced. Some of its characteristics should remain unchanged; the invariants may consist of both the elements of the system and the properties or relations constituting that system. Simplification includes the following main procedures of cartographic generalization: (a) elimination of some elements of the system modelled, some properties of those elements and some relations between them; (b) aggregation, i.e., combining of the subsets of neighbouring elements into a whole; (c) simplification of spatial configuration; (d) grouping the elements' properties. Simplification of the system does not include the procedures which have traditionally been identified with generalization, such as displacement, exaggeration or other ways of bringing out mapped details.

Paradoxically, the concept of cartographic generalization has little in common with the concept of generalization in logic and philosophy. Induction is the process of drawing general conclusions from particular statements about the empirically observed facts. Only grouping of the mapped objects' properties encompasses cognitional procedures of classification, typology and ordering, all of which are inductive generalizations in the sense implied by logic.

Judging from the way in which it is presented in manuals, one might think that mapmaking consists in the synthesis of generalization (reduction of information) and symbolization (graphical coding). The Ratajski's theory of points of change for methods in thematic cartography (1970b) could be quoted as an argument in favour of that approach. It would be more accurate, however, to speak about the synthesis of procedures conducive to the amplification and simplification of knowledge of mapped reality. A good example of how these two aspects of mapmaking intermingle is provided by the preparation of a map which would regionalize some multidimensional phenomenon. The whole procedure of mapmaking is a series of operations aimed at amplifying, simplifying and symbolizing source information producing new, cognitionally valuable information.

Mapmaking includes cognitional acts of two kinds: (1) heuristic acts of creative thinking, and (2) algorithmic acts. The elements of mapmaking, considered as a process of *creative thinking,* represent mutually related mental operations of extrapolation, interpolation, analysis and classification, synthesis, abstraction, induction and comparison.

Mapmaking may also be regarded as *information processing*. This term is used to denote the operations which make it possible to derive from the information on some state of affairs the information on the state of affairs which depends upon said states, the output being already implicated by both the information processed and the rules of processing. The operations of information processing are algorithmic, i.e., they follow strict rules which ensure that the output is correct as, for instance, the rules of calculating arithmetic mean or determining quantiles.

There are some typically cartographic methods of information processing which are certainly cognitional and provide new information about reality. The following examples may be quoted: different methods of interpolation in isarithmic mapping, centrograms, the technique of preparing potential maps, spatial filtering (J. E. Robinson's), cartographic methods of mapping spatial concentration (for instance, Uhorczak's method), determination of class limits in choropleth mapping, and Bertin's method of typifying the data by using the matrix analysis (not totally algorithmized).

The value of cognitive information produced in the process of mapmaking depends to a large extend on both mapmaker's knowledge and his methods of processing the source information: the value put on resultant information, presented in the form of a map, depends on its novelty and its usefulness to map user. The map is evaluated subjectively and different map users may evaluate the map differently.

The Ratajski's model (1977) which reflects both information losses and gains in cartographic communication is closer to reality than Salichtchev's concept and the concept propounded by other representatives of cognitive approach who state that each process of mapmaking is inseparable from producing new knowledge of reality.

3.3. THE PROCESS OF MAP USING

Figure 27 presents a schematic diagram of the procedure which consists in using a cartographic model in order to attain new knowledge. Map reading and measuring provide map user with information I_M about the investigated system. The researcher manipulates the information he obtained by deriving the one he needed I_K from the store of his knowledge. As a result of processing and

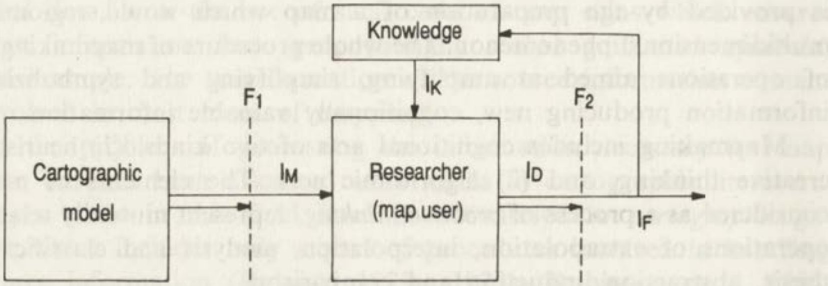

Fig. 27. Research by means of a map

I_M – primary information obtained from map reading, I_K – information used to elaborate and process I_M, I_D – derivative information. Other symbols are explained on the fig. 25

interpretation of primary information I_M, derivative information I_D is produced. The final set of information I_F is part of information which serves the research goals of the map user. This part of information simultaneously builds up his knowledge. Filters F_1 and F_2 stand for information losses that occur if map user may not be able to use the information he derived from the research cartographic model and perhaps not actually need all the information to pursue his scientific or practical goal.

Cognitive process may still take another course if a cartographic model is used for field survey (fig. 28). In that case, a researcher who undertakes observations and measuring has the model of the object researched at his disposal. Cartographic model is used already at the preparatory stage of the research which involves an initial study of the object and the elaboration of research techniques. Apart from that, cartographic model is used in the course of field observations and measuring as well as manipulating the data obtained. I_M stands for the information obtained by means of the model, and I_E for the information obtained as a result of empirical research. The sum of information $I_M \cup I_E$ is then manipulated according to the purpose of the research; in the process, the researcher draws on his knowledge to gain information I_K.

The information I_P is the result of processing and interpretation of the research findings (i.e., the information $I_M \cup I_E$). Information set I_F is the final result which can be presented in the form of a text, a table, a mathematical formula, a graphic image or output as a data file. The information produced enriches the researcher's knowledge and makes it possible to verify the

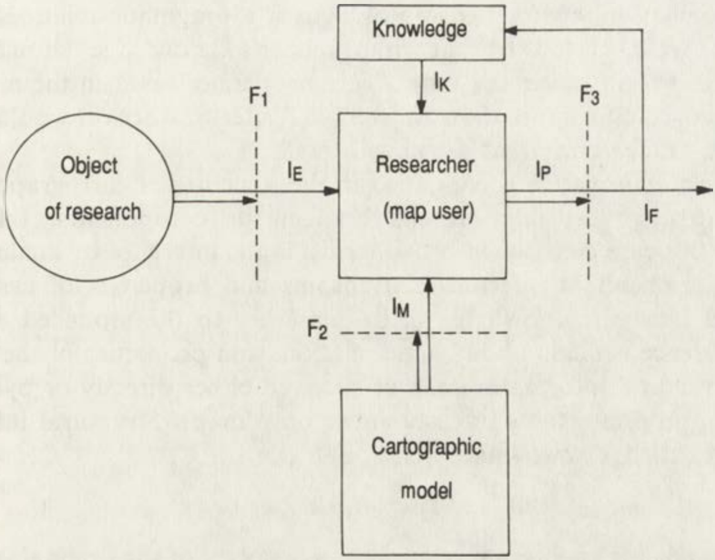

Fig. 28. Empirical research with the assistance of a map

I_M – information obtained by research of a map, I_K – information used to elaborate and process $I_E \cup I_M$, I_P – information resulting from elaborating and processing $I_E \cup I_M$. Other symbols are explained on the fig. 25

cartographic model (its accuracy is increased and its content is extended).

The essence of the use of maps always consists in producing cognitionally valuable information, its value being a pragmatic concept, that is one relating to the knowledge and needs of map users.

3.4. PRIMARY INFORMATION

A map user who reads a map perceives and comprehends the meaning of particular signs and the complexes (combinations) of signs. Within the *primary informaion* I_P which is gained by *map reading*, two kinds of information can be distinguished: semantic information and structural information. The signs constituting the elements of cartographic model themselves contain *semantic information* and this can be expressed by the following formula:

$$I_1 = \langle x,\ t \rangle,$$

where x stands for the signified object, and t – for sign token which is a three-place relation:

$$t = \langle g,\ l,\ m \rangle,$$

where g stands for graphic form of the sign, l – for location of the token on the map, and m – for the meaning of the sign, i.e., its content.

In order to read semantic information it is necessary to have sign competence, that is, first of all to know semantic rules recorded in the legend which assign definite meanings to signs. Whereas the meaning of signs is a semantic relation, comprehension of signs is a pragmatic relation. For that reason the role played by the map reader's knowledge should not be disregarded. For instance, the term "Tertiary period" used in the map legend would tell a geologist more than an average reader to whom it would mean no more than "older period of Cainozoic era".

Structural information is contained in the structure of cartographic model, i.e., in the countless relationships between its components. Information reading in this case consists, in broad terms, in the inference by analogy. From the information about internal relationships and properties of cartographic model and from the knowledge of its similarity to the modelled reality the logical inference is made about some relations and properties of the modelled system. Structural information can be received either directly or by means of applying appropriate tools (measurement on a map). Structural information can be presented as two-place relation:

$$I_2 = \langle R, R' \rangle,$$

where R stands for an internal relation or a property of the original, and R' for the corresponding relation or property of the model.

Structural information can be obtained in two ways. The first one consists in measuring distances, directions, areas and sizes of the graduated symbols on a map. Measurement on a map is a cognitive procedure which assigns numerical measures to the properties of mapped objects. The other way to obtain structural information involves making the inference from the knowledge of the syntactic relations which occur on a map about relations holding in the mapped empirical system. The premises are supplied by visual observation and sometimes by measurement on a map. If the connections between empirical system and its cartographic model are known, then the conclusions about reality can be correct. In this case the information is gained by reading syntactic information, i.e., the one contained in the relationships between signs, and semantic information must be understood before the structural information can be comprehended.

To read and understand structural information map reader has to apply both his general cartographic knowledge and the knowledge of rules guiding the construction of a given map (scale, projection, graduated symbols scaling). Structural information obtained in that way, just as the semantic one, is a pragmatic concept. If the same combinations of signs are comprehended by the readers whose extent of knowledge differ the information they get about the mapped reality may not be identical.

Structural information can be read at different levels. Elementary relationships between objects are read at the lowest level. From general map, for instance, such two-place relations can be read as: "Żelazowa Wola is located near Warsaw", "Warsaw is bigger than Cracow", "Zakopane is located at higher altitude than Warsaw", etc.

At the intermediate levels of reading (if map content is complex) the information is perceived only partially and it is confined to the group of homogenous elements of map content. From a general map, for instance, the locations of mountain areas (represented with reddish colours) and lowlands (represented with green colours) can be read.

At the highest level, the perception and understanding of the relationships is overall (cf. Bertin 1967). Analytical maps with simple content fulfil those conditions. While reading a choropleth, an isopleth, or a dot map it is possible, already at first glance, to get the answer to the question, how the phenomena are distributed over the whole area.

The phenomena represented on complex maps cannot be perceived as a whole. Overall comprehension of the structure requires many acts of partial perception. Sometimes before an overall image of the mapped system can appear in the reader's mind strenuous and comprehensive research is necessary. Theoretically, even an infinite quantity of structural information about modelled reality can be derived from cartographic model. All the iconic models such as a photography, a maquette, a replica of the work of art, and a diagram reveal information in a similar way.

Before information is produced at higher levels of map reading, mental processes of analysis and synthesis of the visually perceived signals should occur. Map reader also makes comparisons in order to discover the relations of similarity or difference between objects mapped, their order or proportions of one object to another.

The information obtained as a result of a complex process of map reading is not the sum of pieces of information as both the overall and partial reception of structural information involves its simplification (receptive generalization). The image of the researched phenomenon obtained by the map reader is general as compared with the multitude of properties and relations recorded on cartographic model. On a dot map, for instance, a reader identifies the main areas of population concentration without having analyzed locational relationships among all the dots.

3.5. DERIVATIVE INFORMATION

When a map reader draws conclusions which enrich the primary information by using his knowledge then a new kind of information is produced, the so-called derivative information. All the knowledge that goes beyond semantic and structural information and is obtained by means of empirical research on cartographic model can be regarded as derivative information; it can be produced thanks to the competence of the knower who further transforms the primary information on the mapped system.

The operations of transformation of primary information into derivative information may be divided into: (a) the operations of information processing, and (b) the acts of creative thinking, that is reasoning. In the process, map user draws on his knowledge of the subject and employs some methods or algorithms. The typical methods of processing primary cartographic information, obtained through map measurement, include: morphometric analysis, statistical and mathematical methods (e.g., regression analysis, factor analysis, trend surface analysis).

Creative thinking includes all the cognitive processes which are not based on the infallible procedures which would ensure the attainment of the intended cognitional goal. Those acts are aimed at generalization, identification of the empirical regularities and the explanation of the mapped phenomena.

A sequence of acts which involves passing from the initial cognitional statements (premises) to other statements (conclusions) is called *reasoning*. Several kinds of reasoning are distinguished: conclusion, proof, generalization, explanation, construction and testing hypotheses, prognostication (Pasenkiewicz 1979). New cognitional statements are derived by the map user from the premises following from his reading of the map (i.e., from the sentences describing some real states of affairs) and from his old knowledge. The concept of "map interpretation" used in cartographic literature is not unequivocal (cf. *Multilingual Dictionary of Technical Terms in Cartography* 1973, Töpfer 1972, Pravda 1975, Ratajski 1977, Witt 1979). The term "map interpretation" generally denotes explaining and clarifying the content of map as well as giving one's comments on it.

I propose that the term of *map interpretation* should be used to denote all kinds of reasoning which would lead a map user, relying on the information obtained from the map (and probably transformed) and derived from his old knowledge, to the conclusions that would enrich his knowledge of the subject. In that sense, the term "interpretation" is not synonymous with the term "explanation", but the former is superordinate relative to the latter. Apart from explaining mapped phenomena, map interpretation would also comprise each reasoning which aims at the formulation of new conjectures, hypotheses and statements, and also at the demonstration or verification of statements.

Logic distinguishes deductive, reductive and inductive kinds of reasoning (Ajdukiewicz 1974). Only deductive reasoning is reliable as the truth of its premises warrants the truth of its conclusion. On the opposite, reductive and inductive reasonings are theoretically fallible as their conclusions may prove false even if the premises were true. To be reliable, those types of reasoning have to meet certain requirements: empirical data (their premises) must be adequately selected and the inferences (the hypotheses) must be verified.

The inference[8] is called *deductive* if the conclusion ensues from the premise. Any reasoning which involves such an inference is deductive. An example of

[8] Inference is the intellectual act of more or less resolute acceptance of the conclusion reached from the already accepted premises. Inference concludes the reasoning and simultaneously constitutes its main part.

such reasoning: "The Amazon basin is overgrown by an evergreen tropical forest" (the premise follows from the land cover map) then "Amazon basin has a hot and humid tropical climate". The other premise from which the inference has been made has not been mentioned and it consists in a general causal relationship: "Evergreen tropical forests occur in the region of hot and humid tropical climate". This reasoning is based on logical law which states that the second proposition of an implication follows from the implication and its first proposition.

In deduction, the degree of certainty of conclusion is equal to the degree of certainty of its premises. If the first proposition (a sentence describing a specific phenomenon on the basis of cartographic model) is accepted as certain by the map user, and the second proposition is an empirical, universally recognized law, for instance in geography, then he can be convinced that his inference is true.

A reasoning is called *reductive* if a premise is the consequence of the conclusion (if B follows from A, then from the consequence B the inference is made that A occurs). These reasonings are reductive which involve reductive inferences. An example of such reasoning: "The mountain valley X is U-shaped in cross-section" (the premise read from contour map), then "X is the poduct of glacial erosion". This reductive reasoning is based on the following causal relationship: "Gouging action of a valley glacier gives the valley a characteristic shape with a level floor and steep sides". The reductive reasoning is fallible and may lead to a false conclusion should the cause of the observed phenomenon be different. And yet, the inferences of this kind, based on the relationship between reasons and consequence which is warranted by some well known, empirically tested law or regularity are common and frequently occur in acquisition of knowledge.

Spatial interpretation of flat cartographic model is another example of reductive reasoning on the basis of facts (premises) obtained from a map. Although colloquially they say that the information about land-surface form or tectonic structures results from the map reading, it should be more adequate to say about an interpretation of topographic or geological maps.

Inductive reasoning consists in the generalization from what has been ascertained in particular cases. Statement on particular facts are the premises, and universal regularity is the conclusion. The statement set out as a result of inductive inferences and reasonings are called empirical laws.

In the process of map interpretation, induction leads to the generalization of fact read from a map. Induction is used to investigate correlation between some phenomena which may be represented on a map, e.g., yield and precipitation. If on the grounds of a set of measurement points some phenomena are found to be strongly correlated, a corresponding statement is formulated and then it is generalized upon the whole investigated area.

Induction is easier to make if the treatment of the subject matter of thematic maps is causative, i.e., the represented phenomena are connected by a casual relationship (e.g., the deposits of mineral resources are shown against the background of tectonics). Thus, the author of the map provides prepared premises from which a map reader can generalize.

Empirical sciences aim, in the first instance, at identifying and explaining regularities, the role of inductive reasoning being essential. The significance of cartographic model is the greatest at the stage of generalizing about particulars and at the stage of deriving geographical regularities from those particulars.

Explanation is a kind of reasoning which aims at answering the question: why is it so and so? Explanation in one of the most important acts of acquiring knowledge and is ranked among reductive reasonings (Nowak 1985, Pasenkiewicz 1979).

Let's assume that having read the map of vegetation in Africa a map user is to explain why savannas occur in the region of the Sudan. He would quote the natural law, accepted in geography of vegetation, stating that climatic conditions (warm climate with a distinctly marked dry season), are the cause, i.e., they are the necessary condition to the development of the plant formations composed of grass with scattered trees, i.e., savannas.

The reasoning by which an individual event is explained with a general scientific law and a statement that the event named in the first proposition of the law has occurred is called a *deductive-nomological explanation*[9] (Nowak 1985). The explanation is called *causal explanation* if the law (as in the above example) is general causal law.

Explanations may often be incomplete which occurs when not all the factors constituting the necessary condition of the explained facts are mentioned (Nowak 1985). For instance, only an approximate list of pertaining factors can be given to explain a complex cartographic pattern of world population density resulting from socio-historical processes and natural conditions.

Genetic explanation has an important property: the facts explained constitute a final stage in a series of previous states of affairs. In order to explain a state of affairs represented on a map conclusions must be drawn on at least some crucial consecutive facts which occurred in a given empirical system in the past. This kind of explanation may occur in the interpretation of geological or historical maps.

Prediction is another act of map interpretation. Prediction based on scientific knowledge is called prognosis. Prognostic reasoning is based on the premises of two kinds: (a) known laws and regularities concerning predicted phenomena; and (b) known past or present states of the phenomena.

A map user can infer that something may happen in the future, i.e. predict, from the detailed information he gained from the map (or a sequence of maps) and from his general knowledge. For instance, a meteorologist is able to prepare a weather forecast by interpreting the sequence of weather charts as he

[9] "Nomological" means: "pertaining to scientific laws".

knows the physical laws which describe the processes in the atmosphere. In this case we have to do with deductive-nomological prediction, its logical schema being similar to the schema of deductive-nomological explanatory reasoning.

Prognoses are fallible, even if, theoretically, prognostic reasoning itself is infallible. This may by caused by: (1) incomplete knowledge of prognosticated phenomena, e.g., weather charts are simplified models of meteorological phenomena; (2) the laws and regularities governing a prognosticated phenomenon have not been known sufficiently. As a consequence, prognoses and predictions are credible only to some degree and they have such cognitional value as hypotheses, suppositions, etc.

There are also various other kinds of prediction (cf. Nowak 1985) which apply to map interpretation. *Extrapolation of trends* is one of them. By comparing a series of maps representing a phenomenon or by analyzing a "dynamic map" some development trends of the mapped phenomena can be identified. The extrapolation of the established trends allows to predict the future state of phenomena. The maps of isopores (annual variations of magnetic declination), maps of vertical movement of the Earth's crust and seismic maps are interpreted just in that way.

Probabilistic prediction consists in determining the probability of predicted phenomena. This can be done on the basis of special climatological maps which show the probability of different meteorological phenomena.

Prediction can also be based on analogical inference. Then it can be predicted that the phenomenon represented on a map will take the same course as it has taken in another cases. For instance, in interpreting the map of forest damage caused by industrial pollution it can be inferred that heavily damaged tree stands will perish.

Map interpretation also involves *prediction on the basis of plans*. The road maps which indicate roads under construction and the years their completion is envisaged enable such predictions.

Prediction may refer not only to the future phenomena. In broad terms, it can be said that certain phenomena which exist at the present time but which have not been known yet can be predicted thanks to the knowledge of some other phenomena that have already been studied. For instance, the use of geological maps, combined with the knowledge on the relationship between the occurrence of deposits and the geological structure, can serve as the basis of search for the deposits.

4. DEFINITION OF MAP

Multilingual Dictionary of Technical Terms in Cartography (1973) gives the following English language definition of map: "Map. A representation, normally to scale and on a flat medium, of a selection of material or abstract features on, or in relation to, the surface of the Earth or of a celestial body".

The definition quoted above, just as many other definitions of map, can be said to state how the term "map" has traditionally been understood by cartographers (cf. Imhof's classical definition 1950). It gives the term "representation" which is superordinate to the term "map" and specifies the subjects to which the map refers ("selection of material or abstract features on [...] the surface of the Earth [...]"). Then the definition enumerates the features defining the concept of map. Planarity is a characteristic feature of syntactic structure of map. Scale and generalization (the equivalents of the term "generalized" occur only in the German and Russian language version of the definition) are semantic properties. Other linguistic versions mention also a pragmatic feature, i.e., the one of "explaining".

The set of all the properties constituting the connotation of the concept of the map is very large. Witt (1979, 622–623) enumerates ten essential properties of map. Berlyant (1973) produced another set of ten properties (cf. 1.3.2). This means that more properties were included than their minimum number necessary and sufficient to give the definition. Definitions tend to be constructed with the use of such a number of properties which equals the minimum number required to explain the essence in the simplest possible way.

Scope of the concept of "map" is vague to some degree as it cannot always make it clear whether a given representation is or is not a map (cf. Bunge 1962). The traditional definition of map preserves some vagueness of the term defined and it also has some features of a regulating definition. According to the traditional definition, the representations which lack some features in the set of defining properties, such as plastic relief maps, globes, star charts, sketch maps, cartograms, and medieval *T in O maps* of the world, cannot be acknowledged to be maps.

The meaning of the term "map", implied by its traditional definition, did not match theoretical assumptions underlying new research orientations in cartography. For that reason attempts have been made to define the concept of map by applying a new conceptual framework produced outside cartography.

The authors of those attempts assumed that they would identify the most essential properties of map by defining either the cartographic form of communication or the cartographic model of reality or the expression governed by the rules of a definite cartographic signs language.

Although Bertin (1967) does not give the definition of map, the meaning he gives to this term can be easily formulated. His concept of "graphic construction" is superordinate to map ("topography"), the primary graphic elements of that construction being two dimensions of the plane, colour, value, size, shape, texture, and orientation. The feature which makes map distinct from any other graphic representation consists in the fact that locational relationships on a plane represent locational relationships on the Earth's surface.

The definition proposed by Gołaski (1973) states that "Map is the means of transmission of the topographic information which tends to inform only by means of signs presented on the plane and designating various objects".

A separate group of definitions consists of the definitions proposed by Stams (1971), Pápay (1972), Aslanikashvili (1974) and Salichtchev (1976, 1982); all those definitions characterize map as model (cf. 1.3.2 and 1.3.3).

Although at present traditional definitions of map no longer reflect the current state of knowledge non-traditional definitions are still unsatisfactory. They are inadequate (usually too broad) and incomprehensible as some terms used in the definiens are incomprehensible to recipients of the definitions. The deficiencies of those definitions, meant to reinterpret the term "map" can be attributed to the fact that the definitions were put forward at an early stage of the development of research orientations in cartography (the theory of cartographic communication and cognitive conception). Although some progress has been made in the study of the properties of map its existing definitions have not been formulated again.

Systematic analysis of the properties and the structure of cartographic model in the present work makes it possible to propose a new definition of map. It will not be confined to the enumeration of a minimum number of defining properties, but it will comprise the set of properties which are the most essential to map as model, i.e., to the map's cognitive function. The set has there basic kinds of semiotic properties: syntactic, semantic and pragmatic.

In order to formulate a new definition it is necessary to apply appropriate conceptual framework, borrowed from semiotics, set theory and the theory of relations. Thus, the proposed definitions is an *explication* (the term coined by R. Carnap) which makes the traditional concept of "map" clear as the language used by it is new and employs scientific terms borrowed from languages which are external to the language of cartography.

To secure the intersubjective communicability of the term "map" auxiliary definitions of such terms as: "real system" "model", "graphic model", "symbolic-iconic model", "coded model", "homomorphism" and "correspondence" must be given. They are necessary to make the main explication unequivocal. Auxiliary definitions given below are regulating definitions which establish efficiently distinct meanings of the terms used in the main definition. More detailed characteristics of the terms explained were given in Chapter 2 of the present work.

1. Model is an object (system) the investigation of which makes it possible to gain the information on another object (system).

2. Graphic model is a model composed of signs which are combinations of the primary graphic elements: colour, value, size, shape, texture, orientation and two-dimensional property of location.

3. Symbolic-iconic model is a model composed of symbols (i.e., arbitrary signs) and iconic signs (i.e., the signs whose relationship to the objects designated is based on similarity relationship).

4. Coded model is a model constructed of signs according to the conventional rules which establish how those signs should be combined into complex expressions and interpreted.

5. Real system is a fragment of reality, considered as a relational system, i.e., a set of elements and a set of relations defined on that set.

6. Correspondence is such a mapping of one relational system on another that the relationships in the second system are uniquely associated with relationships in the first system.

7. Homomorphism is one-to-one mapping of one relational system on another that relationships in the first system are uniquely associated with relationships in the second system.

Now we shall give the explication of the concept of "map":

Map is the model of a real system; the model has the following properties: (1) it is graphic; (2) it is symbolic-iconic; (3) it is coded; (4) the relationship of similarity between modelled system and map is either homomorphism or correspondence; (5) two-dimensional configuration of sign tokens represents positional relationships of the elements of the modelled system on the Earth's surface, another celestical body or celestial sphere; (6) another relationships among signs express different relationships between elements of the modelled system.

In the above explication the concept of map has been modified. The newly constructed concept reflects to some extent the intuitive meanings given to the term "map". "Model" is a superordinate (generic) concept employed in the definition. Thanks to the use of this term, taken from philosophy and methodology of sciences, the definition can grasp the nature of map more accurately than the traditional definitions which usually employed such generic terms as "representation" or "cartographic representation".

Some theses that follow the explication can be either agreeable with the traditional definition of map concept or contradictory to it:

(a) Cartographic model may not be planar;

(b) Cartographic model may or may not be a reduction to scale;

(c) Cartographic model may not be explained;

(d) Cartographic model is a simplified, i.e., generalized image of reality.

By virtue of traditional definition, plastic relief map, globe and polyhedric globe cannot be ranked among maps as they lack one defining property of map – planarity. The extension of the explication encompasses the above mentioned kinds of cartographic representations as the configuration of sign tokens on their surfaces expresses – in a given projection – positional relationships among objects on the Earth's surface.

Star charts, although they do not have a definite scale, can be ranked among maps in accordance with the explication. Also, a lot of early maps, not based on topographic surveys, do not fulfil the condition of reduction to scale. In spite of that, they satisfy the above mentioned, more general condition of the explication according to which the mapping of certain positional relationships between the elements of real system must be correspondence or homomorphism.

Photomaps and some pictorial maps have no explanation. In this instance the codification mentioned in the explication has the form of unwritten agreement, because the iconic signs and the universally comprehensible symbols do not need an explanation.

The explication obviously remains free from the logical contradiction which is implied by traditional definition as the way in which the terms: "plastic relief map", "star chart", "early map", "pictorial map" have been coined, proves that they are subordinate to the term "map".

According to the explication, tactile maps for the blind do not rank among maps as their syntactic properties differ from the properties of maps – visual representations. For this reason the explication may be regarded as too narrow and may need reformulation on the grounds of the detailed study of the tactile maps.

Digital map, i.e., the map image stored in digital form will fulfil the conditions of the definition only after the map image has been projected or printed in a graphic output device.

As models fail to express the entire complexity of the original abstraction and idealization are always implicit in modelling. As "model" is a superordinate term to the term "map" in the explication this also implies that the selection of information is an essential property of map. The properties of homomorphism and correspondence which are characteristic of the relation between the mapped system and the map imply that the mapped objects are classified.

To conclude this chapter, it is appropriate to emphasize the fact that formalized rules of the system analysis used in this work made it possible to define constituting properties of cartographic model and at the same time disregard nonessential details (consequential properties). The above definition of map can be said to constitute an integral part of the presented system of the interrelated concepts which were used for describing map as model.

CONCLUDING REMARKS

Systems analysis applied in this work made it possible to describe map as model and formulate three laws pertaining to relations between the three variables which characterize map as system: elements, properties and relations. Systems approach proved useful in resolving the problems of theoretical cartography. The following suggestions can be made with respect to the application of this method.

Systems analysis of research orientations in cartography: Let us consider, for instance, the concept of "cartographic language". The first step to be made is to identify the constitutive property of the system. That property could consist in the effective communication of the spatial information with cartographic language. Then the structure of the system, i.e., the set of relations corresponding to the constituting property of the system should be defined. All the connections between the elements of cartographic language are analyzed at the following planes: lexical, morphological, syntactic, and stylistic (Pravda 1982). The system's structure should include only those connections which are relevant for the optimization of its communicative function. Finally, the elements of the system should be defined, i.e., the set of cartographic language units in which the relations constituting the structure of the system are established.

Systems analysis of cartographic methods: Choroplethic method, for instance, may be characterized in the following way: relation *R* which orders a set of colours or textures according to their intensity is a constituting relation of the system. Therefore, the colours or textures simultaneously play the role of properties *P* constituting the system. They are assigned to the elements of system *M*, i.e., with unit areas. The set of unit areas is divided into classes and each class is symbolized by another area symbol.

Analysis of cartographic generalization as the system's simplification: In the case of generalization of choropleth map two kinds of simplification are possible:

1. Aggregation of unit areas which implies that the elements and the structure of the system are transformed, whereas its properties are the invariants of the simplification (class intervals remain unchanged);
2. Reorganization of the constituting relation of the system by means of uniting classes. In that case, as the number of classes is reduced the number of properties constituting that system is reduced as well, whereas the elements of the system (unit areas) are invariants of the simplification.

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KARTOGRAFICZNY MODEL RZECZYWISTOŚCI

STRUKTURA I WŁASNOŚCI

STRESZCZENIE

I. W ostatnim 25-leciu w kartografii powstało wiele *orientacji problemowych*, spośród których najważniejsze są dwie: *komunikacyjna* (tzw. teoria przekazu kartograficznego) i *teoriopoznawcza* (tzw. koncepcja poznawcza). Pierwsza traktuje kartografię jako naukę zajmującą się procesem przekazywania informacji za pośrednictwem mapy. Druga – jako naukę, której przedmiotem zainteresowania jest proces poznawania rzeczywistości za pośrednictwem mapy, przy czym opiera się ona na założeniu, że mapa stanowi model rzeczywistości (por. A. Czerny 1990).

W latach sześćdziesiątych kartografowie zwrócili uwagę na modelowy charakter map (por. N. Stefanow 1964, Ch. Board 1967, K.A. Saliszczew, B. Koen 1968, A. Asłanikaszwili 1968). Dotychczas ukazało się ok. 20 prac dotyczących map jako modeli rzeczywistości, takich autorów jak A.M. Berlant, N.W. Fadiejewa, G. Hake, J. Krcho, R. Ogrissek, W. Ostrowski, G. Pápay, W. Stams, C. Steurer, J.J. Szyriajew, A.S. Wasmut i W. Witt. Tezę o modelowym charakterze mapy przyjmują obecnie zarówno zwolennicy orientacji teoriopoznawczej, jak i komunikacyjnej.

Celem niniejszej pracy jest rozwinięcie w pełniejszą i lepiej uzasadnioną teorię założenia, że mapa jest modelem rzeczywistości. *Pojęcie modelu* można wyjaśnić w ten sposób: między modelem M, podmiotem poznającym K a przedmiotem poznawanym O zachodzi relacja poznawcza $R(M, K, O)$. M jest modelem O wtedy i tylko wtedy, gdy istnieje taki podmiot poznający K, że M jest badany przez K, a zarazem K uzyskuje informacje o O (przy czym $M \neq O$).

II. Kartograficzny model rzeczywistości (mapę) można rozpatrywać jako *system*. A.I. Ujomow (1977, 1978) definiuje system następująco: *Przedmioty M tworzą system, jeżeli posiadają pewne własności P, które pozostają w określonej relacji R między sobą.* Definicji tej odpowiada formuła:

$$(M)S = R[(M)P], \quad (1)$$

w której M oznacza zbiór elementów systemu, P – własności charakteryzujące elementy M, R – relację zachodzącą między tymi własnościami, a S – cechę charakteryzującą zbiór M jako system.

Mapa jest systemem w postaci określonej formułą (1), gdzie R oznacza relację modelowania kartograficznego, a P – zbiór cech dystynktywnych znaków kartograficznych, stanowiących elementy składowe mapy.

Relacja modelowania kartograficznego R jest złożoną relacją przyporządkowania. Składają się na nią kompleksy relacji $K_1, K_2, \ldots, K_n$, które są złożone z jednej relacji przyporządkowania i pary relacji porównywania: $K_i = \langle R_i, S_i, S_i' \rangle$. Relacje porównywania zachodzą między cechami elementów graficznych mapy i między różnorodnymi cechami kartowanych obiektów. Przykłady takich par relacji: „na wschód" i „na prawo", „liczniejszy" i „większy".

W zbiorze *P cech dystynktywnych* znaków kartograficznych można wyróżnić siedem rodzajów cech: kształt, rozmiar, orientację, kolor, walor, deseń i dwuwymiarową cechę położenia (por. J. Bertin 1967). Zbiór M egzemplarzy znaków kartograficznych, będących elementami modelu kartograficznego, jest systemem dlatego, że posiadają one cechy dystynktywne P, które znajdują

się w ustalonych relacjach między nimi a cechami elementów składowych modelowanej rzeczywistości.

Druga, równoważna definicja systemu brzmi: *Przedmioty M tworzą system wtedy, gdy zachodzi między nimi pewna relacja R, mająca określoną własność P.*
Można zapisać ją w postaci:

(2) $$(M)S=[R(M)]P.$$

Mapa, rozpatrywana jako system, służy do osiągnięcia określonego celu, a mianowicie dostarcza ona informacji o rzeczywistości. Kartograficzny model rzeczywistości tworzy system w postaci opisanej formułą (2), ponieważ między egzemplarzami znaków kartograficznych, stanowiących elementy M systemu, występują pewne relacje, dzięki którym model może spełniać cel poznawczy. W tym przypadku rolę cechy P tworzącej system odgrywa *własność optymalnego spełniania funkcji poznawczej.*

Do zbioru relacji R, tworzących strukturę systemu, należą:
R_{I} – relacje syntaktyczne, zachodzące między znakami na mapie (w szczególności relacje równoważnościowe, porządkujące i stosunki wielkościowe), które umożliwiają odwzorowanie analogicznych relacji między obiektami w rzeczywistości.
R_{II} – relacje semantyczne, zachodzące między znakami kartograficznymi a obiektami. Należą do nich: *stosunek obrazowania*, którego podstawą jest podobieństwo między znakiem (zwanym wówczas ikonicznym) a oznaczonym obiektem oraz *stosunek symbolizowania*, który zachodzi wtedy, gdy związek między znakiem (tzw. symbolem) a obiektem został ustanowiony arbitralnie, bez względu na podobieństwo między nimi. Znaki ikoniczne warunkują naoczność mapy, a znaki symboliczne – jej abstrakcyjność.
R_{III} – relacja pragmatyczna *kodyfikacji* zachodzi na płaszczyźnie znak – użytkownik. Polega ona na umowie (wyraźnej, wyrażonej w legendzie mapy lub domyślnej), która ustala reguły interpretacji znaków, obowiązujące wszystkich użytkowników mapy.

Mapę można także opisać jako system, podając własności formalne relacji zachodzących między jego elementami. W tym przypadku system jest opisany formułą (2), przy czym symbol P reprezentuje własność *homomorfizmu* lub *korespondencji*, która przysługuje relacjom R, zachodzącym między elementami M modelu kartograficznego.

Odwzorowanie zbioru kartowanych obiektów na zbiór elementów modelu kartograficznego $f\colon A \underset{na}{\rightarrow} A'$ spełnia zatem następujący warunek:

dla dowolnych x, $y \in A$ i x', $y' \in A'$
takich, że $f(x)=x'$ i $f(y)=y'$ zawsze
jeżeli $R(x, y)$ to $R'(x', y')$ lub
jeżeli $R'(x', y')$ to $R(x, y)$.

Zatem zachodzenie relacji $R(x, y)$ między dowolnymi obiektami jest albo warunkiem koniecznym, albo warunkiem wystarczającym zachodzenia odpowiedniej relacji $R'(x', y')$ między elementami modelu kartograficznego.

W pierwszym przypadku zachodzi homomorfizm relacji, w drugim zaś korespondencja. Odwzorowanie relacji równoważnościowych spełnia warunki homomorfizmu, natomiast odwzorowanie relacji porządkujących jest korespondencją. W szczególnych przypadkach odwzorowanie może być zarazem homomorfizmem i korespondencją (tzw. *homomorfizm silny*) lub izomorfizmem. Nieformalnym przykładem *izomorfizmu* (identyczności) relacji przestrzennych jest mapa wielkoskalowa, którą traktujemy jako podobny geometrycznie obraz terenu.

III. *Funkcja poznawcza modelu kartograficznego* polega na uzyskiwaniu nowych, wartościowych informacji o rzeczywistości i jest realizowana już na etapie opracowania mapy, na którym występują trzy rodzaje operacji, prowadzących do przekształcenia informacji źródłowych:
1. Symbolizacja – kodowanie graficzne, tj. przekształcenie formalne informacji;
2. Generalizacja – uproszczenie modelowanego systemu empirycznego;
3. Operacje wzbogacające informację o modelowanej rzeczywistości: (a) czynności myślowe

o charakterze algorytmicznym (przetwarzanie informacji); (b) czynności myślowe o charakterze heurystycznym (myślenie twórcze).

Proces użytkowania mapy obejmuje czytanie oraz interpretację mapy. Model kartograficzny dostarcza trzech rodzajów informacji:

1. Informacja *semantyczna* jest wynikiem zrozumienia znaczenia znaków kartograficznych;
2. Informacja *strukturalna* powstaje w wyniku wnioskowania przez analogię;
3. Informacja *pochodna* jest rezultatem interpretacji mapy, tzn. przetwarzania odczytanej z mapy informacji pierwotnej (semantycznej lub strukturalnej).

IV. Następująca eksplikacja stanowi modyfikację i uściślenie pojęcia mapy jako modelu rzeczywistości:

Mapa jest modelem układu rzeczywistego, charakteryzującym się następującym zespołem cech: (1) jest graficzny, (2) jest symboliczno-ikoniczny, (3) jest skodyfikowany, (4) relacja podobieństwa zachodząca pomiędzy układem modelowanym a mapą jest homomorfizmem albo korespondencją, (5) dwuwymiarowa konfiguracja egzemplarzy znaków odwzorowuje relacje położenia elementów modelowanego układu względem powierzchni Ziemi, innego ciała niebieskiego lub sfery niebieskiej, (6) inne relacje między znakami wyrażają różnorodne relacje między elementami układu rzeczywistego.

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