SYSTEM APPROACH TO R2V CONVERSION FOR ANALYTICAL GIS

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ABSTRACT

We present a system approach to automatic digitization of raster-scanned color cartographic maps. This approach contains all three steps involved in digitizing process: pre-processing, processing and post-processing. Up-to-date systems for vectorization raster maps using automatic or semi-automated programs essentially carry out only one kind of operation: they follow discrete points along a curve (tracing, snapping), or attempt to combine automatic and interactive tasks, if the tracing is met the ambiguities. In our proposal, the automation problem is approached from a unified point of view, leading to the development of software A2R2V (Analytical Raster-to-Vector) conversion that is capable to recognize and vector a maximum number of cartographic patterns into raster maps. We propose some strategies for solving the problem and illustrate it, describing single modules of A2R2V system. The place of the operator and knowledge in a R2Vconversion system is considered as well.

KEY WORDS

Geographical Information System, raster-to-vector conversion, cartographic pattern recognition.

1 INTRODUCTION

The problem of automatic raster-to-vector (R2V) conversion is taken steadfast attention by researchers and software developers during last two decades. Numerous attempts to solve this problem have mainly originated from emerging area of automatic Geographical Information Systems (GIS). Unfortunately, completely automatic conversion system appears unrealistic and some authors suggested putting the operator into the center of a conversion system. Amazingly, this idea was independently expressed by the different authors with the same words from the Lukas' Gospel [1, 2]. Now the problem is which part of conversion process should be carried out by the operator and which part by the machine?

In the present work we analyze (keeping certain skepticism) the degree of possible automation of the single modules of a raster-to-vector conversion system. Mainly, we focus on the case of analytical GIS (the case of register GIS is considered in [2]). We believe that these two cases are representative enough and complement each other, constituting a complete description of both research and commercial (semi) automatic R2V conversion systems.

As we previously stated, the present work is clearly divided into two parts: 1) in Sections 1-4 we analyze the general concepts of automation of a R2V conversion system that are constituted the system approach; 2) in Section 5 we overview A2R2V conversion system in which we placed the ideas of our system approach. In Section 6 we emphasize the role of knowledge in automation of the conversion process.

The process of developing of a GIS can be represented by the following set of steps [1]:

1. State of the problem.
2. Definition of the methods for solution of stated problem.
3. Preparation of the input information required for solution of the stated problem by the defined methods.
4. Definition of the composition and logical structure of the cartographic data.
5. Analysis of existing cartographic information.

5.1 Recollection of the vector maps, which can be used in the GIS.

5.2 Definition of the vector map layers, which can be directly elaborated by the geodesic data.

5.3 Definition of the paper and raster maps for vectorization.

6. Designing the cartographic base for the GIS.

6.1 Inclusion of existent vector maps in the GIS.

6.2 Digitization of new cartographic materials.

6.3 Designing vector map layers by the geodesic data.

6.4 Unification of the vector map layers (conjunction of fragments, unification of the cartographic projection, elimination of logically contradicted data, etc.).

7. Designing vector thematic maps.
8. Solution of the stated problem.
9. Publication of the results.

Clearly the labor required for each of the steps listed above depends on the qualitative and quantitative characteristics of the cartographic materials used. These can be combined into a single index: *novelty*. Thus, we can classify a GIS into one of four novelty levels (in decreasing order of index):

A. A new vector cartographic material is required. However, for the territory under consideration only paper maps exist in the desired scale.
B. Basic vector cartographic materials exist for the territory under consideration, but there are not thematic maps of the desired type.
C. Thematic vector cartographic materials have been produced in a previous GIS for the territory under consideration. The new GIS are to be developed under the assumption of some fundamental changes.
D. Updating and development of an existing GIS without essential changes.

GIS with novelty level A and B require relatively more labor for the digitization of paper and raster maps than the others do [1]. Generally speaking, topographic and thematic vector-based maps have been produced for the territories in small-scale. Current GIS-development is directed towards problems in urban planning, emergency situation monitoring, election enumeration and other government activities that require the maps in big-scale. To carry out these projects, the volume of labor involved in the digitization of paper and raster maps is considerable, even if only the largest urban areas of a country are considered. Clearly the development of these problem-oriented GIS can only be completed if the task of vectorizing traditional cartographic materials is automated to the fullest extent possible.

Two main technologies[6] are currently used for map vectorization [1]: *(V1) Paper map digitization by electronic-mechanical digitizers*, and *(V2) Raster map (a map obtained after scanning of the paper original) digitization.*

The process of digitizing paper maps cannot be automated; hence we suggest that the only practical approach to design GIS's is the development of new methods and software to automate vectorization of raster maps.

Raster map digitization technologies can be divided into four intersecting groups [1]: *(D1) Manual; (D2) Interactive; (D3) Semi-automated, and (D4) Automatic.*

In practice, manual raster map digitization methods (D1) coincide with paper map digitization methods (V1). A few examples will serve to illustrate this. In the case of punctual objects, the operator visually locates graphic symbols and fixes their coordinates. In the case of linear and polygonal objects, the operator uses rectilinear segments to approximate curvilinear contours. The manual digitization rate is one to two objects per minute.

Interactive digitization uses special programs, which, once the operator indicates the starting point on a line segment, automatically follow the contours of the line (*tracing*). These programs are capable of tracing relatively simple lines. If the program cannot solve a graphical ambiguity on the raster map, it returns a message to the operator. Recently, vector editors capable of carrying out this digitization process have appeared, reducing the time consumption by a factor of 1.5 to 2. These can be called semi-automated systems[7] [1, 2, 8, 9].

In theory, automatic digitization vector editors automatically digitize all objects of a given class, leaving the operator to correct errors in the resulting vector layers. The most popular vector editors use this approach. However, in practice, the high error level resulting from any small complication in the raster map means that alternative methods must be sought to reduce the high volume of manual corrections. It should be noted that the use of increasingly complex methods and algorithms for machine recognition of cartographic objects does not materially improve the results [1] (Cf. [4]). Why?

We suggested [1] that the answer is the development of a system approach to automatic map digitization, which uses the basic domination principle: *"And he said unto them, 'Render therefore unto Caesar the things, which be Caesar's, and unto God the things, which be God's.' "*[8] (Cf. [2]). In the other words, methods and software should be developed which leave to the human operator only those tasks, which the computer cannot carry out. In the present case, this implies a detailed analysis of all existing map digitization processes, and the development of software to automate all technological vectorization operations, based on formal, heuristic, knowledge and interactive algorithms, which can effectively be used by the computer.

The above thesis is especially suitable for analytical GIS in contrast to register GIS, as the former do not require an extremely high level of geometric exactness in the cartographic materials, whereas they do require fast processing of a large number of vector layers. An example of analytical GIS is a GIS developed to solve territorial planning problems, while an example of a register GIS is GIS developed for a cadastral system. Our approach is effective for both types of GIS. However, the reader may think about the analytical GIS first.

[6] Or types of source data captur ing from maps. Other data types commonly used in GIS are survey da ta, aero and satellite images, etc.

[7] Notice that the interactive and semi -automated modes can coincide if they are executed in real-time. Ot herwise we consider them as two different tasks

[8] The Gospel from Lukas

An application of such system approach can greatly enhance the outcome not only of *processing*, the main stage of cartographic image recognition, itself, but also *pre-processing* (preparation of paper maps and their raster analogues) and *post-processing* (final processing of the results of automatic digitization)[9]. Thus, in the following three sections we shall consider all these processing as parts of the system approach.

2 RASTER MAP PRE-PROCESSING

The main goal of *pre-processing* is to prepare raster cartographic images in such a way as to simplify them and increase the reliability of their recognition in the automatic system.

Notation	Degree
Software for automation of the operation already exists	100
The operation can essentially be automated	75
The operation can be automated	50
The operation can partially be automated	25
The operation cannot be automated	0

Table 1. The degree of automation of raster-to-vector conversion operations.

Pre-processing operation	Degree
1. Preparation of the cartographic materials for scanning	
1.1 Restoration	0
1.2 Copying	0
1.3 Increasing the contrast of image objects	0
2. Scanning	
2.1 Test scanning	0
2.2 Definition of the optimal scanning parameters	50
2.3 Final scanning	0
2.4 Joining raster facets	100
2.5 Correction of the raster image geometry by the reference points	100
3. Preparation of the raster maps for recognition of the cartographic objects	
3.1 Edition of raster map	
3.1.1 Elimination of the map notations and map legend	25
3.1.2 Elimination of the artificial objects and restoration covering by them images	25
3.1.3 Restoration of the topology of cartographic images in pixel level	100
3.2 Separation of basic colors of the graphical codification on a raster map	75
3.3 Restoration of the color palette of a raster map	75
3.4 Stratification of raster map	
3.4.1 Stratification by reduced color palette	75
3.4.2 Logical stratification of the cartographic objects	25

Table 2. The degree of possible automation of pre-processing operations.

[9] These general definitions of proces sing steps will be particularized in Section 5

Table 2 represents the proposed sequence of operations for the preparation of raster maps for automatic recognition and our very subjective opinion on their possible automation degree, using the notations given in Table 1[10].

Restoration. Paper maps subject to storage and use show signs of wear on their surfaces; spots, scratches, and even notations. Even maps drawn on more stable media, such as cardboard, Mylar, organic glass, or aluminum are subject to the same defects. These signs of wear should be eliminated wherever possible; otherwise they impede the automatic recognition of cartographic features.

Copying. If the designer of a GIS project has copying equipment and the GIS is "analytical" not "register", then both manual and automatic vectorization are usually performed on copies of the map rather than on the original. The advantages include preservation of the original, parallel processing of the vectorization by several manual operators and registration of the graphical singularities of the objects of a given class for further processing of the copy.

Increasing the contrast of image objects. To simplify the process of vectorization, objects of the same class can be highlighted on a copy of the map using a contrasting color. Typically such marking involves enclosing linear objects such as rivers, roads or pipelines. In practice, outlines of polygonal objects, which do not have explicit borders (such as bogs, bushes, etc.), and are delineated only by dashed or patterned lines, must be drawn in. In particular, various polygonal objects may overlap, one represented by color, another outlined by a dashed line, and a third by patterned lines; in such cases, the objects must all be outlined explicitly.

Definition of the optimal scanning parameters. Both existing research and our experience in image recognition show that the efficiency of object identification depends on the choice of scanning parameters. Candidates are resolution, color palette, contrast, brightness, and visual effects. It is known that an optimal set of scanning parameters exists both for every scanner and for each map to be scanned [5]. The parameter set can only be tested by repeated test scans followed by visual or automatic analysis of the raster images obtained. An objective justification of the choice of optimal scanning parameters can be obtained by statistical calculation of the raster characteristics. Criteria for estimating the statistics can be developed from the point of view of effectiveness of the cartographic image recognition.

[10] It would be interesting in the context of present work to compare not only the degree of automation of different procedures, but also their relative durations. This comparison w ill be a topic of our subsequent paper. In this work we may assume that the time is not essence for A2R2V conversion (however it may be so for a particular GIS-application)

Joining raster facets. The necessity of joining raster facets arises due to two main reasons; first, large-scale scanners are very expensive, and most users do not have access to them, and second, the cartographic materials required for the GIS-development often have different standards for different scales. In the present work, we may assume that software is available which can edge-match raster facets with minimal errors [4, 5].

Correction of the raster image geometry by the reference points. In practice, the raster image obtained after scanning is not uniformly deformed, due to printing errors, wear, scanning errors, and defects in edge-matching. Raster transformation programs exist to eliminate or at least minimize these defects. This has the direct effect of increasing the accuracy of the vectorization of the final map and the indirect effect of ultimately improving image recognition. The *general principle of raster map correction* is that of plane transformation by reference points, i.e. displacement of certain points of the raster map those coordinates are known; followed by translation of the remaining elements of the raster correspondingly. Reliability of raster map correction is maximized when geodesic reference points are used as the control points. A satisfactory correction to the raster map can be provided by a coordinate grid on the original map. In this case, if the type and parameters of the cartographic projection are known, programs can be developed which generate a theoretically exact system of the reference points used for transformation of the raster map. If neither geodesic data nor a coordinate grid are available, larger-scale or same-scale vector maps which have already been corrected, or satellite images containing the reference points can successfully be used to correct the raster map. In this case, punctual features of the cartographic objects, such as river confluence's, road intersections, bridges, etc. can be chosen as control points.

Elimination of map notations and legend. After scanning, a raster map contains much graphical information that it is not necessary to vector, such as toponimics, annotations, explanations, copyright notice, etc. This information must be eliminated to simplify cartographic image recognition. The map legend must also be eliminated, and processed as a separate raster image.

Elimination of artifacts. Artifacts (traces of folds, stains, scratches, dust, etc.), which contain no information, are nearly always present on a raster map, and complicate subsequent cartographic object recognition. A difficulty in processing artifacts is the necessity of restoring the image previously covered by the artifact.

Restoration of the topology of cartographic images. As a result of printing and scanning errors, graphical images of the cartographic objects on a raster map frequently have topological defects. Typical defects are breaks in thin lines, which should be continuous (such as contour lines, rivers, etc.) and the fusion of lines that logically should not intersect (e.g. contour lines). Topological errors in raster images complicate the recognition of cartographic objects, and gross errors, which can be noted by visual analysis of a raster map, must be corrected before the automatic recognition procedure is begun. The difficulty of solving this problem is increased due to the fact that such defects are often only visible, and can only be corrected, at the pixel level. Nevertheless, powerful programs for correction of raster maps at pixel level currently exist, providing hope for the solution of this problem [1, 4, 5].

Separation of basic colors. In graphical coding systems for cartographic information, a limited number of colors are used for a given map. However, after scanning, a raster map contains a large palette of colors, complicating image recognition. Analysis of the map legend colors and selection of the best quality segments in the raster field aid in reconstructing the basic graphical coding palette. Superfluous colors and their shades can then be substituted by the corresponding elements of the basic palette.

Stratification of raster map. A raster map, considered as a unified heterogeneous graphical image, is suitable for parallel human vision. In contrast, raster images, containing homogeneous graphical information, are suited to consecutive machine vision. Two approaches can be used for the stratification of the original raster map: 1) *stratification by reduced color palette* or 2) *logical stratification of the cartographic objects*.

In the first case, maps are derived from the original raster map which preserve only those pixels which have a strongly defined set of colors corresponding to the images of one class (for example, red and yellow, say, might correspond to the icons of populated places and the color of their outlines). In the second case, the map only preserves fragments of general raster images corresponding to the locations of cartographic objects of one class (for example, railways with adjacent thin zones).

The procedure of stratification by color is clear, therefore let us consider here the basic features of logical stratification of a raster map. The *principle* is that the presence of a cartographic object, which must be vectored in logically separated layers, is reliably known. Thus, the only task left for the recognition program is specification of the location of the object. This simplifies the problem and increases the reliability of the solution. Logical stratification of a raster map can be done manually. The operator moves a window of given size and shape, separating the fragments of the layer formed. The efficiency of logical stratification, even when performed manually, lies in that the main difficulty in vectoring raster maps is visual fixing of the coordinates of an object. In practice, this means that the operator must change the scale of the image and fix its coordinates using the cursor, perhaps two or three times, until a satisfactory result is obtained. On the other hand, defining the location of the object by specifying the size of a window is easier, especially when it is taken into consideration that the operator need not be concerned with any overlap of raster map facets, since the program can correct for this.

A typical situation that may arise is that a small-scale map already exists for a given territory. In this case, for logical stratification of a raster map, one must use methods for constructing buffer zones of the linear objects. These are already available in some popular vector editors [21].

3 RASTER MAP PROCESSING

The main goal of this principal stage of automatic vectorization of raster maps is the recognition of cartographic images; i.e. generation of vector layers and attribute information in electronic maps. From our point of view, the most promising line of software development is the development of methods, algorithms and programs that focus on locating and identifying specific cartographic objects. Each cartographic image has its own graphical representation parameters, which can be used for automatic object recognition on a raster map. The particular attributes depend on the topological class of the object. In traditional GIS, vector map objects are divided into *three types*: points, arcs and polygons, representing respectively punctual, linear and area objects. This classification can easily be extended to the analysis of cartographic images in raster maps. Objects are drawn on thematic maps in the form of graphical symbols, which are the same for all objects in a given group. Graphical images have geometric (location), topological and attribute (quantitative and qualitative parameters) information, which we can combine to form the *concept of a cartographic image*. The main geographical coding attributes of cartographic images of the three classes are shown in Table 3.

<table>
<tr><th>Object</th><th colspan="4">Attributes of the graphical representation</th></tr>
<tr><td>Point</td><td colspan="4">Form
Size
Painting</td></tr>
<tr><td>Arc</td><td colspan="4">Type
Color
Thickness</td></tr>
<tr><td rowspan="3">Polygon</td><td colspan="3">Area</td><td>Contours</td></tr>
<tr><td>Filling</td><td>Dash</td><td>Crape</td><td rowspan="2">Type
Color
Thickness</td></tr>
<tr><td>Color</td><td>Type
Color
Thickness
Inclination
Density</td><td>Form
Size
Painting
Density</td></tr>
</table>

Table 3. Main attributes used for graphical coding of cartographic images.

The classification of cartographic images is different when the vectorization of raster maps is considered. All objects on a raster map have area, and in this sense they are all polygons. It is not an easy problem to reduce the graphical coding elements of cartographic images to elements that correspond to the geometric categories "point" (a coordinate pair), "line" (a sequence of coordinate pairs) and "polygon" (a closed set of line segments which do not intersect and form the border of a geometrical figure). However, the classification of punctual, linear and polygonal objects must be preserved, because we can omit the relative stretch of the cartographic images in one or two directions (respectively lines or points) with respect to the stretch of the map field. A recognition program that recognizes, for example, punctual objects, does not have to distinguish between the punctual cartographic image itself or an element of a polygon fill pattern.

Notice that there may be other graphical objects involved in recognition of cartographic images, which are nearly always present in raster maps. Principally, these are letters and digits (toponimic, quantitative and qualitative characteristics of objects). Additionally, there may be other graphical elements in the map (footnotes to lines, insets, etc.) It is thus convenient to use the classification presented in Table 4.

Recognized object	**Cartographic images and their elements**
Point	*Images of punctual objects* Polygon crape
Arc	*Images of linear objects* Explicit polygon contours Dashed lines
Polygon	*Images of polygonal objects with implicit contours given by:* • Filling • Dash • Crape
Text	• Toponimics • Altitude marks of relieve • Road distances • Parameter values on the isolines • Passport characteristics of geodesic points and hydrometric posts, etc.
Additional graphics	• Text footnotes • Guidelines • Berg-dashes of relieve isolines • Circular diagrams, etc.

Table 4. Cartographic object classificati on from automatic vectorization point of view.

An important element of the automation of raster map vectorization is the development of an optimal sequence of steps for cartographic image recognition, successively eliminating elements already decoded from the raster map field and restoring images, which were hidden by the eliminated elements. The *basic principle* of this optimized ordering must be "from simple to complex". Nevertheless, the possibility of using information from objects already digitized (whether manually or by an automatic system) must be provided for in the development of a recognition strategy. For example, the punctual layer of hydrological monitoring posts can be successfully used for recognition of linear elements of the river network. Moreover, the symbols of these posts generally cover images of the river, complicating automatic identification of the rivers. Taking this into account, it becomes clear that hydrological monitoring posts must be vectored before the river network is digitized. Eliminating them from the raster map, one can use their locations and attribute data (mainly altitude marks) to aid in recognition of elements of the river network.

Further developing this approach, it is suggested to use already existing small-scale vector maps for recognition of corresponding cartographic images on large-scale maps. A small-scale map contains generalized (in a broad sense) information about a considerable proportion of the objects on the corresponding large-scale map. As a rule, the generalization involved in decreasing the map scale consists in the simplification of the geometric shape of the object and the elimination of a part of the object. For example, on a large-scale map, a river is represented by a polygon, but on the small-scale map, as a line. In general, a given object can be expected to change in topological type when the degree of generalization changes. Even if the topological type of an object is preserved after generalization, several objects on a large-scale map may correspond to a single object on a small-scale map. Examples of the correspondence between the objects in maps of different scales are presented in Table 5.

Scale		Examples	
Fine	*Coarse*	*Fine*	*Coarse*
Point	Point	Altitude marks of relieve	Altitude marks of relieve
	Line	Out of scale irrigation massif	Irrigation channels
	Polygon	Out of scale habitual point	Territory of habitual point
Line	Point	Linear rows of pores	Single pores
	Line	Line of electric transmission	Line of electric transmission
	Polygon	Line of riverbed	River water area
Polygon	Point	Territory of water supply	Single pores
	Line	Territory of water supply	Linear rows of pores
	Polygon	Bog territory	Bog regions

Table 5. Correspondence of cartographic objects in maps of different scales.

The use of small-scale maps solves a difficult problem in automatic digitization: the search for objects in the whole raster map field. In this case, a vectored object can be found in the nearest neighborhood of its generalized analogue, and nowhere else.

The search zone for paired punctual objects can be restricted to a circle with a radius defined by the correlation between the scales of the vectored maps and the maps used.

We suggest the use of the *"caterpillar" algorithm* (the name reflects the shape of the illustrated algorithm) for searching for paired linear objects. The caterpillar algorithm involves the construction of a system of line segments perpendicular to the contour of their small-scale analogue, divided in half by it. The length of each segment can be chosen by the correlation between the scales of the maps used and their density, i.e. by the curvature of the generalized line. Moreover, the search object is located along segments constructed in this way. The sequence of reference points of the search curve can thus be found. The reference points obtained can be joined by straight-line segments in an interactive digitization system without any intervention by the operator.

Automatic cartographic image recognition is simplified and its reliability increased by the use of corresponding vector layers of a small-scale map for digitization of isoline and other regular systems of linear objects (such as the coordinate grid, or urban blocks with linear or radial planning). But in this case not all lines of a large-scale map have small-scale analogues. For example, the contour lines on a vectored 1:50,000 map may have 10m density while on the corresponding 1:250,000 map they have 50m density. In such a case, the contour lines that have counterparts in the generalization (0, 50, 100, etc.) are vectored first by the caterpillar algorithm. Next, the *"stairs" algorithm* (the name reflects the shape of the illustrated algorithm) is applied for the recognition of the intermediate contour lines. The stairs algorithm constructs a system of curves between each adjacent pair of already vectored contour lines, which are perpendicular to each of these contour lines. The density of these curves is defined by the curvature of the basic lines, just as in the caterpillar algorithm. Moreover, points of the adjacent contour lines to be searched for are located along the curves constructed in this way. Between two index contour lines, the number of additional lines to be found is well defined (for example, between two contour lines of 100 and 150m four additional contour lines of 110, 120, 130 and 140m always exist and can be found). Once all the required reference points have been found, it is clear that they can be joined in succession using the program tools given by the caterpillar algorithm.

The sequence of reference points of a vectored li[illegible] object can be copied from the layer, which conta[illegible] corresponding punctual objects. For example, shoreline structures (hydrometric monitoring posts, bridges, docks etc.) can be used as reference points to digitize the contours of rivers and lakes. The hydrometric monitoring posts are particularly useful here. Their coordinates and attribute data (name of the river or lake and altitude mark) can be used in automatic recognition algorithms for the elements of the hydrological network on the raster map. Notice that in this case automatic digitizing reverses the order of operations compared to traditional techniques. Traditionally, the operator first digitized the hydrological network manually, and then vectored the location points of the shoreline structures using vector-editing tools.

Operation	Degree
1. Development of the strategy of automatic digitization of raster maps	
2. Definition of sound matrices of raster maps	
2.1 Classification of recognized objects	0
2.2 Definition of the size, form and color filling of basic sound matrices of raster maps	75
2.3 Estimation of statistical weights of single elements of cartographic images	75
3. Recognition of cartographic images	
3.1 Digitization of objects which have vector analogues	75
3.2 Digitization of objects which have not vector analogues	50
3.3 Elimination of superfluous recognized objects	0
4. Recognition of attributive data of vectored objects	
4.1 Classification of attributive information carriers	0
4.2 Localization and identification of attributive information	75
4.3 Correction of errors of attributive data recognition	75
5. Elimination of recognized images from raster map	
5.1 Restoration of image covered by recognized object	75
5.2 Correction of restored image	75

Table 6. The degree of possible automation of the processing operations.

In other words, maximal use of already existing information (directly or indirectly related to the vectored objects) employed as a *general principle of automatic cartographic image recognition* can increase efficiency and reliability. For example, algorithms that use digital models of a region, and that are based on small-scale maps can be produced for digitization of the hydrological network. If the layers are already vectored, this can be used to generate the sequence of reference points of the curves to be recognized; otherwise these points can be indicated manually as described above. This simplifies automatic digitization and increases its reliability.

Summarizing the processing of raster maps, we notice that the methods and algorithms used for this process must provide complete, even redundant cartographic image recognition to eliminate erroneous recognition of objects, since visual control and correction of the vector layers can be carried out more quickly than manual digitization of missed objects.

To conclude the discussion in this section, we notice that the process of automatic cartographic image recognition (processing), from our point of view, should follow the scheme presented in the Table 6, where, as before, we assign scores indicating the degree of possible automation of the various steps involved in processing.

4 RASTER MAP POST-PROCESSING

The main goal of the *post-processing* of raster maps (after cartographic image recognition) is an automatic correction of vectorization errors.

For automatic correction of raster map digitization we suggest *two approaches*: using 1) the topological characteristics of objects in vector layers and 2) the spatial correlation (connectivity) of the corresponding vector layers.

The first approach is based on the fact that many cartographic objects in the system have well-defined topological characteristics, which can be used for the correction of vectorization errors. Let us give some obvious examples.

Isolines. The topological characteristics of isoline systems (for example, contour lines) are: a) isolines are continuous, b) they cannot intersect each other, c) each isoline is either closed or starts and finishes at a domain boundary, and d) polygons which cover the whole domain without intersections can be assembled from the arcs of the correct isoline system together with the domain boundaries. However on a raster map these characteristics, as a rule, may be lost due to several reasons: a) the lines are broken where a parameter value for a given isoline is written, b) some sections of isolines are not well drawn in high density regions, and c) the raster images of some isolines merge due to defects of printing and scanning the paper maps. The "tick marks" (small segments of fixed length, which are perpendicular to the isolines and drawn in the direction of the decreasing of cartographic parameter) need special consideration. These elements of the map's graphical design, if not recognized as the parts of the isoline system, hinder the correct assembly of the polygons and either must be eliminated or (better) detached in a separate vector layer. They can be restored on the vector map and used for the automatic attribution of polygons assembled from the contour lines.

Hydrologic network. The relevant topological characteristics of the hydrological network (rivers, channels, brooks, etc.) are that its vector image, within the limits of each watershed, has the structure of a simple connected directed tree graph. However on raster maps, images of water bodies can be disrupted by images of other types: area (reservoir, cities, etc.) and punctual (populated places, bridges, etc.) that break the structure of the hydrologic network.

Region maps. The topological characteristics of a region map (for example, the map of political division of a country) is that each arc, being a segment of the boundary of a disjoint region, is either closed or starts and finishes at another arc. Thus a correct system of non-intersecting polygons covering the whole surface of the map can be assembled from the boundaries of the regions, adding, if necessary, the domain boundaries. However on the vectored region map, the boundaries of some regions may be discontinuous, impeding the production of the correct map topology.

The second approach is newer and offers more potential. It consists in using connectivity, or spatial correlations among the various vector objects to correct the results of automatic digitization and the attributes of raster map cartographic images. Let us explain this by the following examples.

Hydrosphere elements. The vectored elements of the hydrosphere include objects of all three topological types: polygonal (e.g. seas, lakes, reservoirs, ponds, bogs), linear (e.g. rivers, channels, brooks) and punctual (e.g. springs, out-of-scale reservoirs). It is clear that nearly all hydrosphere elements have certain spatial relationships among one other. For example, springs or lakes can be the sources of rivers (main hydrosphere elements). Linear river sections can connect polygonal hydrosphere elements (extended sections of riverbeds, lakes or reservoirs). Rivers discharge into seas or lakes. These spatial relationships are not only necessary for a topologically correct vector image of the hydrosphere, but can be also used to correct automatic digitization results of the river network, where the digitized polygonal and punctual hydrosphere elements are available.

Relief. The relief of a region on the maps is represented by objects of two topological types: 1) punctual (trigonometric points, hydrometric monitoring posts, reference points with coordinates obtained by the Global Positioning System (GPS)), and 2) linear (contour lines, relief features–slopes, ravines, landslides, etc.). All these objects have correlations among each other due to their location and in particular to the altitudes given as attribute information.

We notice particularly the relationship between altitude and the hydrologic network; altitude decreases monotonically along a river in the direction of flow, thus each contour line intersects the river either not at all or exactly once. Due to this relationship, it is convenient to produce the vector map of the hydrological network before digitizing the contour lines and to subsequently use the digitized hydrological network for correction of the results of contour digitization.

Road network. The road network on the map represents roads, highways and railways of all sizes. Its elements form a graph, the majority of those nodes represent populated places and punctual objects of the transportation infrastructure (e.g. bridges, tunnels, railway crossings, docks, airports) and can be used for the correction of results of the automatic digitization of the road network. Moreover the construction of modern roadways leads to the transformation of the natural relief of the region that, as a rule, is represented by short linear objects, which describe the relief (e.g. embankments, excavations). If these objects are digitized before vectorization, then their geometrical and attribute information can be used in the algorithms to correct results of the automatic digitization of the road network.

Administrative and political divisions. The borders of the administrative and political division of a territory often follow rivers, roads and other linear elements of the cartographic structure. Prior digitization of these elements can be used for the correction of results of automatic digitization of the corresponding layers of raster maps.

The examples presented in this section show that the characteristics of internal structure and relationships between the vector objects can be used effectively in automatic correction of errors of the automatic vectorization of raster maps. In practice it means the development of more specific software for automatic cartographic image recognition.

Summarizing the discussion of this section, we propose that the process of automatic correction of results of automatic cartographic image recognition (post-processing) follows the scheme presented in the following Table 7, where we show, as before, our evaluation of the degree of possible automation of the corresponding procedures, expressed as the scores defined in Table 1.

Operation	Degree
Correction of vector layers based on peculiarities of their internal topology	75
Correction of vector layers based on their spatial and logical correlation with other vector objects	50
Final correction of vector layers in whole electronic map system	0

Table 7. The degree of possible automation of post-processing operations

5 A2R2V

5.1 INTRODUCTION

In this section, we overview single modules of our map interpretation system called *A2R2V* effected to date [3].

5.2 HOW DOES IT WORK?

A2R2V is based on semantic analysis of color images. Semantic analysis of cartographic images is interpreted as a separate representation of cartographic patterns (alphanumeric, punctual, linear, and area). Our map interpretation system explores the idea of synthesis of invariant graphic images at low level processing (vectorization and segmentation). This means that we ran "vectorization-recognition" and "segmentation-interpretation" systems simultaneously. Although these systems can generate some errors, they are much more useful for the following understanding algorithms because its output is nearly recognized objects of interest.

We begun map recognition from global binarization followed by classical OCR-identification with artificial neural networks (ANN), supervised clustering, knowledge-based recognition rules, and morphology-based vectorization. To overcome the problem of labor-intensive training, we designed simplified images. For this purpose, we used the linear combinations of color components or image representations (*false color technique*) and binary representation composing (*composite image technique*). These techniques are application-independent. However, in the frameworks of our approach, map recognition may be treated as a common (application-dependent) task [6]. We followed the concept that the important semantic information necessary to interpret an image is not represented in single pixels but in meaningful image segments and their mutual relations [8].

We set forth a conception of composite image representation and decomposition. The main goal of image decomposition consists of the object linking by its associated names. We use an image synthesis based on object-fitting compact hierarchical segmentation [10]. We perform composite representations (or simply, *composites*) of the source image by means of a reduced number of color or tone components and segments. In this manner, visually perceived objects are not eliminated and the *image's semantics* is preserved. The image's semantics in this context corresponds to the association of segment fields of different hierarchical levels being identified with identifying conceptions from the subject domain. For example, detection of a segment set identifying a coastline or highway becomes semantically meaningful. Further, this set of segments is renamed as "coastline", "highway", etc.

The composite images form a "book" in which the objects of interest can be found and recognized on appropriate page(s). Thus, a "page number" defines the method of thresholding and some tuning parameters (Figure 1).

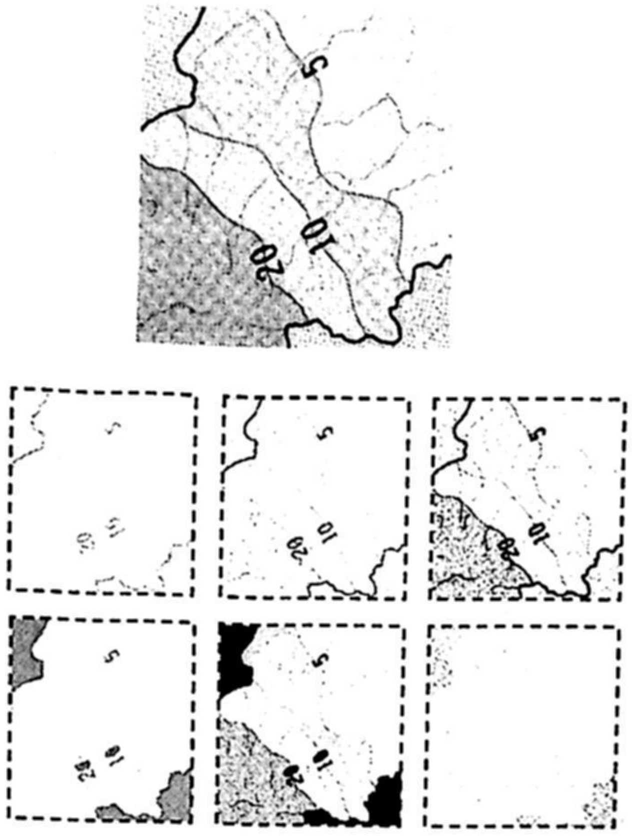


Figure 1. Source image (top) and some "pages" of a "book" of composite images

5.3 SACR

SACR is System of Alphanumeric Character Recognition. We use the false color technique of image segmentation [11], which we aim to separate alphanumeric characters (for subsequent recognition) into raster-scanned color cartographic maps, using model of color *RGB*. Note that this is a very difficult problem because there is either text embedded in graphic components, or text touching graphics. The processed images only maintain pixels that truly belong to objects we wish to segment, eliminating all pixels not of interest that are produced by noise or obtained due to erroneous selection of scan parameters (Figure 2).

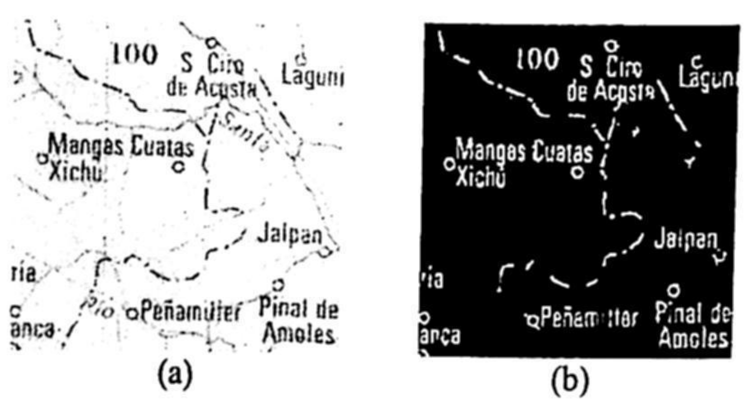


Figure 2. (a) – source image; (b) – segmented image

The following identification of segmented objects is particular, previously prepared application. We first build the strings of characters and use a set of ANN for identification of single letters and gazetteers (toponimic dictionaries) for word identification.

(a) (b)

Table 8. (a) - 16 selected fonts for testing previously trained ANN; (b) – example of inclination of the ch aracters Abadi MT Condensed Light font in the sizes of 13 ÷ 17 points

Moreover, ANN are previously trained on a set of artificially created characters of different fonts, sizes, inclinations, etc. (Table 8). However, we apply these ANN to identification of real characters into cartographic images using 1,025 alphanumeric characters (upper and low cases, different fonts, sizes and inclinations) extracted from real raster maps. 95.5% of which were successfully recognized by the system. A gazetteer is used to verify either an identified string of characters forms meaningful word, or not [3].

5.4 SPOR

SPOR is System of Punctual Object Recognition. This nearly full automatic system, which generates vector layer of punctual cartographic patterns (Figure 3), is described in detail in [1].

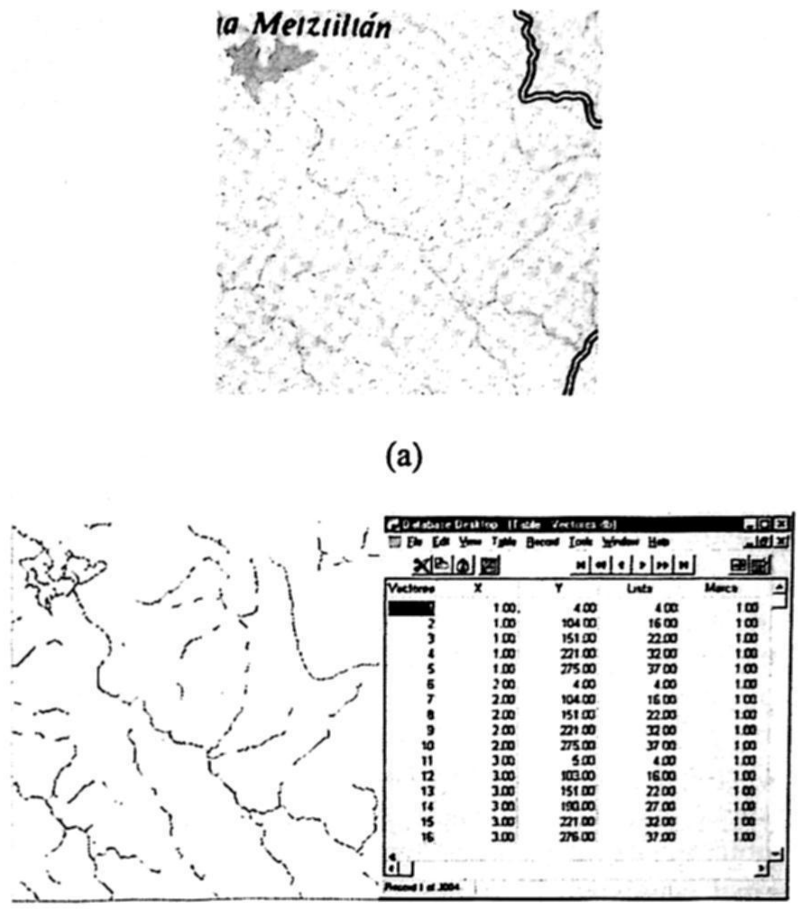
"Blue" palms pixel coordinates: (547,375); (572,378); (590,408); (643,411); (709,417); (697,443)

(a) (b)

Figure 3. (a) – recognized "blue" palm re storation (in white) over source image; (b) – pixel coordi nates of recognized palms

5.5 SLOR

SLOR is System of Linear Object Recognition. This is mainly semi-automated system that provides full image treatment: pre-processing (image enhancement and segmentation), processing (a set of supervised identifiers and knowledge-based recognition rules), and post-processing (morphology-based vectorization). Thus, human-machine interaction is optimized [3]. A result of full processing of linear cartographic patterns is shown in Figure 4.



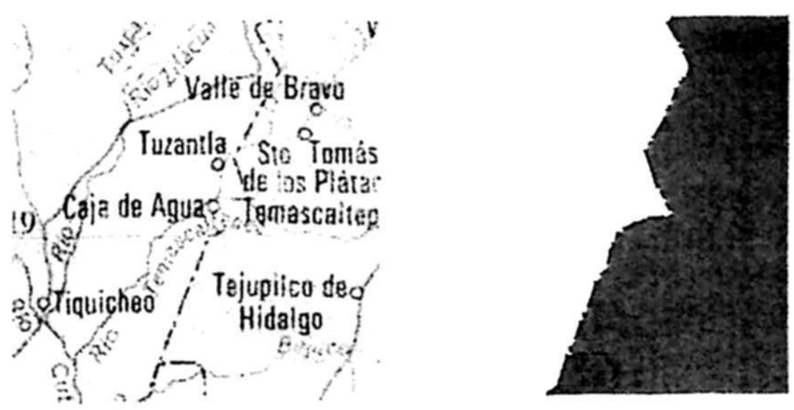
(a)

(b) (c)

Figure 4. (a) – source image; (b) – vector image of rivers; (c) – associated to (b) vector database

5.6 SAOR

SAOR is System of Area Object Recognition. A result of application of composites to an administrative map is shown in Figure 5.



(a) (b)

Figure 5. (a) – source image; (b) – recognized polygons

5.7 COMMENTS AND SECTION 5 SUMMING-UP

(a) We used OCR-identification with ANN in SACR and SPOR systems only, training ANN on sets of artificial characters, but applying them to real map characters; (b) We used perceptron multi layer-multi neuron feed-forward to recognize alphanumeric and punctual characters. In the first segmentation, we selected and labeled the connected components to be analyzed by

ANN; (c) If characters touch graphics, we developed a method to separate and further recognize touching symbols [3, 11]; (d) Size of training set is 95,000 samples; (e) ANN have a special output to show shapes that do not appear to be characters of interest; (f) Linear character recognition does not use OCR; (g) Composites provide area character recognition because segmented area objects are labeled by the system in same, but are different for each type of objects, gray-level values (Section 5.6).

The processing of spatial data is a complicated interaction of the hardware, software, data, methods and people. Following to [7], GIS is a computer system that consists of a database in which the spatial and descriptive information of geographical environment as a part of the real world is stored. Moreover it permits the input, maintenance, analysis, transformation, manipulation and representation of spatial data of some geographical point. The basic element of any GIS is a set of vector cartographic maps. Note that some popular commercial systems are very expensive and often ugly to perform problem-oriented applications due to the absence of format standards, ill representations of spatial databases or impossibility to process color images.

We design A2R2V as a multi-environment system, which does not depend on particular data format and oriented to process color raster-scanned images. Its GUI is described as follows. At low level, it has the modules of automatic recognition of alphanumeric, punctual, linear and area objects into raster-scanned color cartographic images[11], which have been programmed in C. Thus, a database with quantitative, qualitative and nominal features is associated to each recognized visual object! At the intermediate level, a JAVA module supports correct conversion of corresponding database to be processed at high level in one of the environments: UNIX, LINUX or Windows. Hence the user of our system should not seek for unified or particular representation of spatial databases in an environment, but only chooses most convenient one from given three. We are now developing a decision making tool to support most adequate to particular GIS-application user's choice.

In this section, we presented a system for automatic interpretation of raster-scanned color cartographic maps. The highlight of our system is two "intelligent" color image segmentation techniques. They are followed by a set of identifiers that includes classical OCR-identification, supervised clustering, knowledge-based recognition rules, and morphology-based vectorization. The identifiers and vectorization worked well because they receive as input from the segmentation step nearly recognized objects of interest (alphanumerical, punctual, linear, and area). In our experiments, we used complex raster-scanned color cartographic images, which, being intermediate between drawings and natural images provide a nearly ideal model for testing because they have characteristics of both [3].

At the same time, automatic interpretation of color cartographic images presents certain difficulties for state-of-the art in image processing and also artificial intelligence. A set of vector maps that one can expect as an output of such interpretation is very useful for Geographical Information Systems, new map production, and old map actualization. However, it appears unrealistic to obtain a fully automatic computer-based interpretation system free of errors [1-2, 12-16]. Additionally, please note that high efficiency of interpretation is required for vector map production and actualization first. It seems reasonable to obtain in both cases 90÷95% successfully recognized objects. This is to avoid excessive work on corrections of errors produced by the computer system that can sometimes be greater than manual raster-to-vector conversion [17].

We believe that only a system approach to the problem can be fruitful. In the context of the A2R2V system, this means first, decomposition of source image by multiple hierarchical components to achieve a stable, accurate representation in the presence of degraded images. Second is segmentation with mutual recognition of appropriate primitives. Third is the development of a unified knowledge-based learning and self-learning system with optimal human-machine interaction for color cartographic image treatment. Our future research will be concerned with this approach.

Finally, attempting to answer the question stated in Introduction, we define the degree of automation of each module of A2R2V system (in terms of system's errors based on our experimentation) as follows in Table 9[12].

A2R2V module	**Degree of participation (%)**	
	Human	*Machine*
SACR	5÷15	85÷95
SPOR	5÷10	90÷95
SLOR	5÷30	70÷95
SAOR	< 15	> 85

Table 9. Which part of conversion process do the operator and which part by the machine carry out?

6.CONCLUSIONS

Summarizing the analysis of the process of automatic raster map digitization we notice that this problem is of great current interest and we conjecture that the most promising line of progress towards its solution lies in successively increasing automation of the separate links of the system approach considered here. We suggest as a

[11] In the other words, these modules provide raster-to-vector automatic conversion of scanned color cartographic images.

[12] In this work we keep away an important problem of quantitative estimation of the efficiency of the conversion system [2, 18-20]. This problem will be considered in a s ubsequent paper (Cf. footnote 5)

main principle of such automation, maximal use of already existing and reworked vector and attribute information in the preparation, digitization and correction algorithms of each succeeding vector layer. This information can be organized and effectively used as a knowledge base in the conversion system. Thus, the system approach presented here can be combined with knowledge-based approach to R2V conversion. We already included into A2R2V system some elements of "intelligence" to increase its effectiveness. The following examples illustrate this statement: 1) a simple idea to use the gazetteers in SACR increased significantly that system efficiency; 2) the knowledge-based recognition rules combined with morphology-based vectorization in SLOR led to automatic generation of vector databases associated to linear cartographic patterns; 3) the use of knowledge allows to run simultaneously "low-intermediate-high level processing" as in the false color and composite techniques. Now we develop the "fine-to-coarse scale technology" of the conversion in which the "knowledge" of cartographic patterns into small-scale map aids in recognizing the corresponding patterns into large-scale map of the same territory.

[2] stated that an efficient R2V conversion system is not just a union of its parts, but their complex interaction that defines the effectiveness of the system. From our point of view, the best way to design that interaction is the use of knowledge.

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