КАРТОГРАФІЯ І ГЕОІНФОРМАТИКА •
CARTOGRAPHICS AND GEOINFORMATICS

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Classification of Interactive Functions of the Electronic Atlas: Logical Scheme and Outcomes

This paper is the completion of the project started in *[1]*, which is devoted to the development of the classification of interactive functions of the electronic atlas. In the previous work, we developed the theoretical and methodological basis for creating the classification. This paper describes the logical scheme of the classification and the classification groups within the created classification. To detect interactive functions, thirty-four atlases and ten geoportals released between 2006 and 2021 were analyzed. A detailed list of applications can be found at the link: *https://bit.ly/3wL35uu*. Interactive functions mentioned in the literature on the topic were also taken into account. The proposed classification *(https://bit.ly/3Ck3jvK)* is artificial and taxonomic with a combined structure: faceted radial at the first level and sequential within each facet (group). The main (type, class, genus, kind) and transitional (subtype, subgenus) taxonomic categories were allocated, the purpose of which is to emphasize the subordination of the classification groups of objects and to reveal the vertical connections between them. One hundred and eighty-one interactive functions are allocated among seven groups, where each group corresponds to one feature by a purpose: Settings and Support, Visual Design Adaptation, Navigation, Analysis, Extensibility, Recoverability, Saving, and Tracking. The sequence of groups corresponds to the hypothetical stages of the user's work with the electronic atlas and is intended to facilitate the perception of the classification. The classification is open to extension as well as modification for specific thematic atlases. Future additions will include functions with a 3D dimension and an audiovisual component.

Keywords: classification of interactive functions, electronic atlas, taxonomic classification, atlas cartography, interactivity.

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Класифікація інтерактивних функцій електронного атласу: логічна схема та результати

У статті запропоновано класифікацію інтерактивних функцій електронного атласу, теоретико-методологічні засади створення якої були розроблені попередньо *[1]*. Для виявлення та формування множини інтерактивних функцій використано тридцять чотири електронних атласи, десять геопорталів та література за темою. Класифікація є штучною та таксономічною з комбінованою структурою: фасетною радіальною на першому рівні та послідовною всередині кожного фасету (групи). Система ознак класифікації сформована на основі призначення функцій. Виділено сім груп функцій: Підтримка експлуатації, Адаптація візуального дизайну, Навігація, Аналіз, Розширюваність, Відновлюваність, Фіксація досвіду. Кожній групі відповідає одна з ознак за призначенням, а послідовність груп обумовлена гіпотетичним сценарієм роботи користувача з електронним атласом. Класифікація відкрита до розширення та модифікації. Дана робота є першим кроком до створення механізму оцінки інтерактивності електронних атласів.

Ключові слова: класифікація інтерактивних функцій, електронний атлас, таксономічна класифікація, атласна картографія, інтерактивність.

Introduction

Modern atlas cartography has faced a number of challenges: the need to revise the concept of an electronic atlas (EA); improving cartographic visualization (do we need 3D atlases?) and graphical user interface (GUI); increasing the attractiveness of atlases for users (in particular, using a storytelling strategy); providing better interaction between developers and users, etc. These topics have been discussed over the past four years at conferences and seminars of the International Cartographic Association (ICA) and the ICA Commission on Atlases. The discussion that preceded these meetings was reviewed in *[2]*.

Issues related to the interactivity of EAs deserve special attention. As we know, both low interactivity (non-interactive EAs do not exist) and creating EAs with the maximum possible interactivity usually have a negative effect on user interaction with the EA. Therefore, the task arises of finding the optimal interactivity for each EA, taking into account the corresponding category of users of this EA. One of the main indicators in determining EA interactivity is interactive functions (IFs), where each IF denotes the concrete change of the EA representation *[1]*. However, a more perfect source of interactivity evaluation is the classification of IFs, which not only detects and forms a set of IFs but also arranges it ac-

cording to a certain feature (system of features). In addition to the systematization of experience in the creation and implementation of IFs, the classification speeds up the development of EAs by authors-users of the atlas platform (AtP); can be used to demonstrate the interactive capabilities of the AtP; and finally, its creation can contribute to finding new IFs and relations between existing ones, up to revising the theoretical provisions of atlas cartography.

In work *[1]*, we developed the theoretical and methodological basis of the creation of the classification of IFs of the EA. This included the formation of the terminological apparatus of the research object and the classification system; the formation of a set of classification objects; the determination of the kind and structure of the classification; and the development of classification principles and requirements. The classification by kind is special, artificial, intensional, multilevel, empirical, and taxonomic; its structure is combined, namely, faceted and sequential. The scope of the classification is limited to scientific and general-purpose EAs but includes the possibility of modification for EAs of any theme and purpose.

The purpose of this study is to create the classification of interactive functions of the electronic atlas according to the developed logical scheme.

Literature review

The main source for the creation of the two best-known classifications of IFs of the EA can be considered the master's thesis *[3]*, in which forty functions were divided into nine groups. The first classification belongs to F. Ormeling *[4]* and was developed for school EAs in 1996. In addition to the classification itself, F. Ormeling proposed a hierarchy of the most desirable IFs for school EAs. This classification was given a kind of continuation in the work *[5]*, in which "atlas and map use activities" were obtained by combining "map use activities" and functions *[3]*. Highlighting the connections between user tasks and user activities was the main focus of the study.

The most developed is the classification *[6]*, the creation of which was timed to the first version of the electronic Atlas of Switzerland (2000). This classification has undergone two stages of modification. The latest version of the classification *[7]* contains the following groups of functions: General Atlas Functions, Navigation Functions, Cartographic Visualization Functions, Analytic Functions, Information and Didactic Functions. In addition, functions within (sub)groups are divided into func-

tions with basic and advanced interactivity. Basic interactivity includes activities such as general visual inspection and comparison of maps, obtaining certain thematic information, searching and locating places, export the visualization results. Advanced interactivity corresponds to more high-level activities (high-level interaction tasks), including detecting and comparing spatial structures and processes, importing and recalculating data, and working with 3D dimension.

The theoretical and methodological basis of the classification *[7]* is contained in the master's thesis of J. Cron *[8]* and the appendix (catalogue) to it *[9]*, where the composition of each classification group and the functions themselves are described in detail on the following items: definition, implementation, functionality and interactivity, design, and overall assessment. Each function is accompanied by illustrations from twelve EAs that were analyzed to create the classification. However, no clear classification methodology was outlined. This refers to the kind and structure of the classification, the classification features, and relations between classification groups.

Noteworthy is the work of A. Balciunas on the evaluation of the functionality of national atlases' web maps *[10]*, where eight groups of IFs are allocated by purpose: image review, data review, data visualization, composition of map layout, measuring of map elements, management of information resources, using the information (publishing), and data selection and analysis. The refinement of the list of IFs and their detailed description was carried out in the dissertation *[11]*.

Among the classifications of IFs not directly intended for EA, we note the Typology of Interactivity Functions for Visual Map Exploration *[12]*, where seventy IFs are allocated among eight types of inter-action. The typology is based on the interaction operands approach. In other words, the classification feature for grouping functions is the type of object to which the interaction is directed. However, no further division of IFs within the types was performed.

We conducted a more detailed analysis of the above-mentioned classifications in the paper *[1]*, from which it follows that now only the non-alternative classification *[7]* is used. Among its shortcomings, in addition to the indistinct theoretical and methodological basis of creation, it is worth mentioning the insufficient consideration of other views on the concept and interactive capabilities of the EA.

Materials and research methods

The process of classifying the IFs of the EA (Fig. 1) consisted of the following stages: (1) determining whether IFs belong to a set of classification objects according to the developed principles *[1]*; (2) formation of the system of classification features; (3) clarification of the kind and structure of the classification; (4) formation of a system of taxa and allocation of taxonomic categories; and (5) implementation of the classification mechanism (allocation of IFs by classification groups in compliance with the proposed classification rules).

To detect IFs, thirty-four atlases (thirty-one web atlases and three desktop EAs) and ten geoportals released between 2006 and 2021 were analyzed (the list of applications is available at the link: https://bit.ly/3wL35uu). Geoportals (national and regional level) are included in the analysis because they are very similar in concept and set of functions to some modern EAs. We considered EAs created using the same AtP/framework as one atlas solution. These include the atlases of Geoclip and Geodan companies, the atlases of the Federal Statistical Office
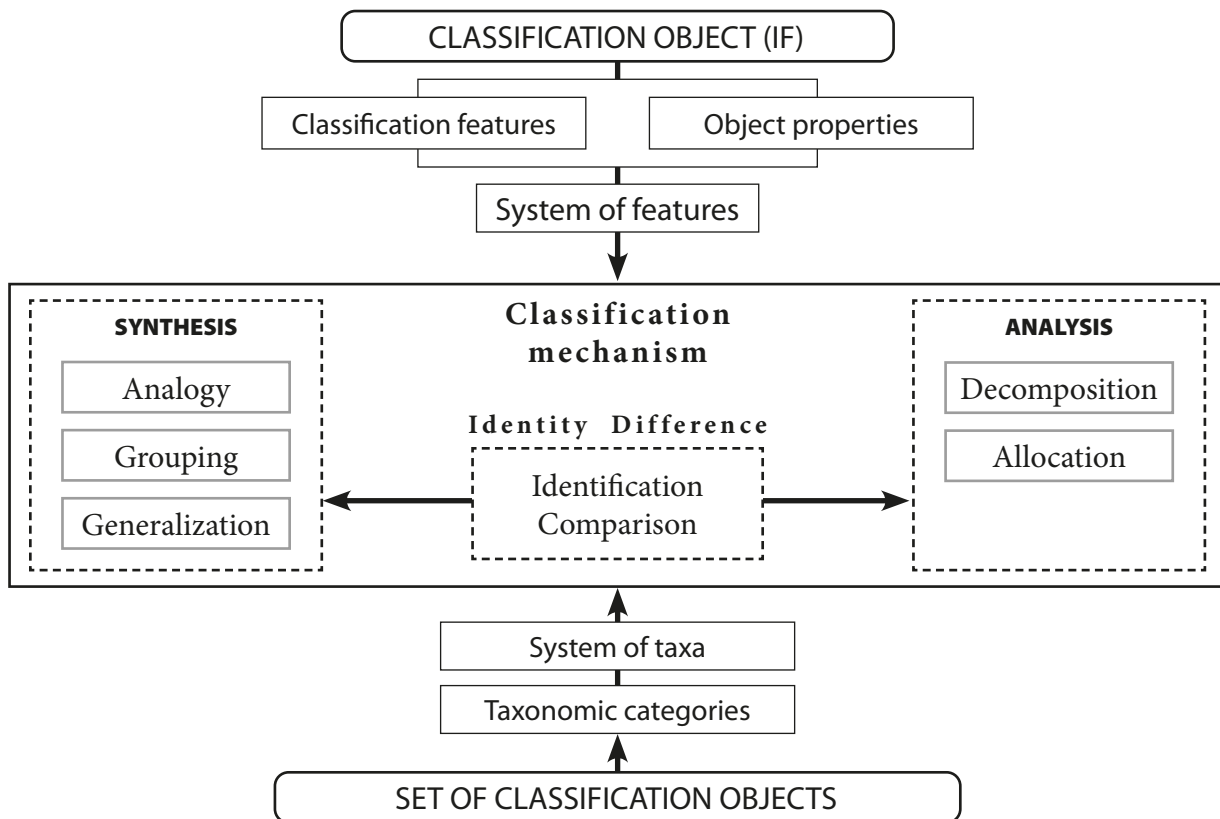

Fig. 1. The logical scheme of classifying the interactive functions of the electronic atlas (adapted from Fig. 1 in *[13]*).

of Switzerland (in particular, the Statistical Atlas of Switzerland), the Ukrainian AtlasSF framework, the Nunaliit Atlas Framework, and others. Among the EAs, we separately note the National Atlas of Hungary, the IPCC WGI Interactive Atlas, STATatlas, the Atlas of Switzerland 3 (2010), and the EAs of the Geoclip company. These atlas solutions were the most informative in detecting IFs and are visual demonstrations of different visions of the EA implementation.

Results and discussion

The formation of the set of classification objects—IFs of the EA—was carried out at the theoretical and methodological stage of the classification development *[1]*. This process first consisted of detecting and then selecting IFs. Thus, the detection implied fixing all the IFs implemented in the reviewed EAs and described in scientific literature on the topic into the form of a list. The selection consisted in the exclusion of IFs according to the following criteria: discrepancy with the purpose and scope of the classification (for example, *Quizzes function or Games function [7]*); discrepancy with the functions and purpose of the EA (for example, complex GIS analysis functions).

The next step was to select the general principle of classifying IFs, according to which the system of classification features was formed. Having considered the varieties of IFs in work *[1]*, we found that IFs can be grouped by origin, purpose, and operand. Grouping by origin and operand, i.e., the object targeted by the IF, enables us to divide IFs by one feature, but further division of IFs within the groups already implies the determination of new classification features. Besides, the detection of the origin of IF is quite ambiguous and debatable. And classifying by operands implies preliminary development of the typology of operands, where the location of IFs among operand types will have to be determined. Further classifying will either not be carried out, as in *[12]*, or will require the allocation of operands at lower hierarchical levels or a mixed approach to classifying.

At first, we created the classification based on the operand using the last two approaches, but we did not get a satisfactory result: many IFs were repeated; there were problems with the differentiation of EA elements (operands), primarily at lower hierarchical levels; in some places, several classification features

(within the type) were formed, which indicated the lack of clarity of features. Instead, the classification of IFs by purpose is more flexible and clear since the features by purpose for each group are different, and the combining of IFs within the group is carried out by one feature.

When developing the system of features by purpose for the classification of IFs of the EA, we set a goal to avoid features that would refer to the origin of IFs or the elements of the EA to which IFs are directed (which is characteristic of the classifications of the above-mentioned authors). It was important to take into account the multifunctionality of the EA, the universality of its interface, and the orientation to work with spatial and non-spatial models of various types, the content of which reveals a specific theme (story) and spatial relations within the modelling territory. At the same time, we kept in mind that the EA is considered as a cartographic application, with the vast majority of its functions related to the manipulation of cartographic models.

So, we have determined as many similarity relations in the set of IFs as possible, where a feature can be considered a feature by purpose (performing a certain action). Then, after selection and generalization of features, the system of features was formed. The system here means that there should be certain relations between the features. After analyzing the selected features, we came to the conclusion that it is advisable to form the system of features taking into account the hypothetical stages of the user's work with EA: familiarization and customization of the EA workspace; search for needed content elements (information); manipulation of content elements (analysis, editing, addition); saving and sharing the results of work with the EA. Having studied

TYPE	NAVIGATION						
SUBTYPE	SPACE						
Class	Zooming	Movement					Centering
Genus	...	*Panning*			*Scrolling*	*Rotation*	...
Subgenus							
Kind	...	Information and namigation structure	Map	...	Information and namigation structure	Text	Map	...

Fig. 2. The sequence of taxonomic categories on the example of the *Navigation group*
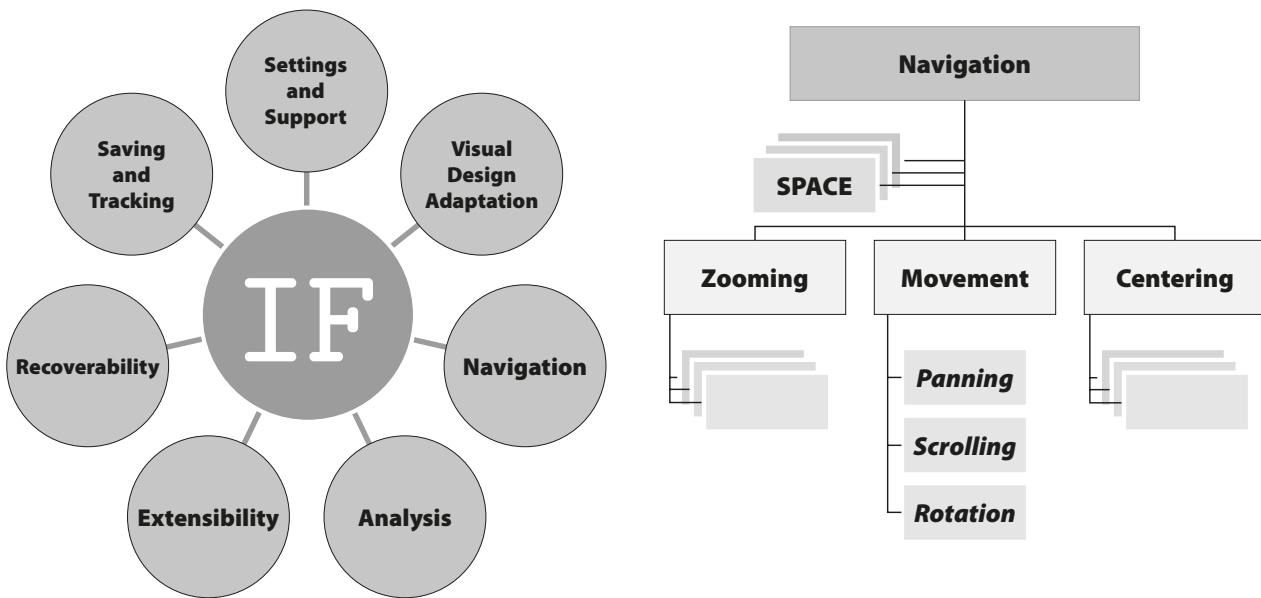
Fig. 3. The faceted radial and sequential structures of the classification system

the relations between IFs and starting from the essence of IFs and the specifics of their composition *[1]*, we were convinced that the classification should be multilevel and taxonomic. The main (type, class, genus, kind) and transitional (subtype, subgenus) taxonomic categories were allocated *(Fig. 2)*. The sequence of classification elements within one taxonomic rank, except for specially indicated cases, was determined according to the principle from general to specific (for example, atlas—information and navigation structure—map—thematic layer) or according to the hypothetical usage scenario of IFs of the EA.

Finally, we have allocated seven classification groups according to features: Settings and Support, Visual Design Adaptation, Navigation, Analysis, Extensibility, Recoverability, Saving and Tracking. The IFs of each of the groups can be applied at any stage, so the sequence of groups should be considered more likely a condition that ensures better perception of the classification and work with it.

The classification structure is combined. At the first level, the faceted form of the structure was chosen. Therefore, the allocation of all selected IFs for each group is carried out according to one of the features by purpose. All groups are represented as separate facets connected to the center (IF) by radial relations; that is, each group is at the same hierarchical level and is independent of the others. The kind of the structure of the separate facet is already sequential, and the principle "each with the previous, each with the next" is fulfilled *(Fig. 3)*.

The essence of the classification mechanism is the detection and allocation of IFs to classification

groups based on the fundamental notions of identity (identification) and difference (comparison) according to selected features. At the same time, classification features and taxonomic categories are organized according to the pyramid principle: the lower the rank of the category, the wider the range of its features (with the obligatory preservation of the main feature of the group). The mechanism of classification is inductive. In other words, it consists in the generalization and synthesis of elements of the set of IFs. But within the classification groups, methods of analysis (decomposition and allocation) are also applied, which is primarily characteristic of the relations between the classification elements of such taxonomic ranks as genus and subgenus and genus and kind.

To meet the requirements of classifying *[1]*, we formulated the following rules for classifying IFs:
1. Limiting the initial set of IFs only to existing ones (implemented or described).
2. Selecting the optimal kind and structure of the classification.
3. Selecting the classification features, which are features by purpose.
4. The names of the classification groups should be general and abstract.
5. The division of IFs within the group is carried out according to the one main feature
6. Limiting the number of classification elements for each of the classification groups to not more than ten and not less than one.
7. The presence of more than ten elements in a group of the same rank requires its division into several groups.

The classification of IFs of the EA is posted in full at the link: https://bit.ly/3Ck3jvK. The classification contains one hundred and eighty-one IFs. The following is a description of the classification groups of IFs.

Settings and Support

The IFs that provide reference and information support for the EA's use session as well as the selection of general settings of the EA. This group of IFs is placed first because most of its IFs are correlated to the tasks that users have at the beginning of the EA's use session: to understand what the EA is about, what its capabilities are, and how to use it. In order to work efficiently and conveniently, it often becomes necessary to select general settings, such as language. And for more experienced users, preparation for working with the EA content can consist in authorization or selection of EA operation modes.

The group contains four classes of IFs, which are placed according to the hypothetical usage scenario of the EA: *Identification*, *About*, *Help*, and *General Settings*. The Identification class contains the IFs of creating, logging in, and logging out of the EA user account. The *Exit function* for desktop EAs also denotes an exit from the application. The *About class* contains IFs, the purpose of which is to tell the user about the EA and provide information about the team of authors and sources used. The *Help class* is formed by the IFs that answer the question "how to use it" and by the prompting IFs. The *Recommendation function* implies that particular content elements may be suggested to the user based on recommendations from the EA developers or other EA users (e.g., by popularity) in general or for the already opened content element. The idea of the *Saving the Representation of the Session's Content Elements function* is described in detail in the "CSP3. View.State" paragraph of the article *[14]*.

Visual Design Adaptation

The IFs that enable users to change the visual design of the EA. Here, we take the view that visual design includes graphic design and interface design. Therefore, we propose to associate everything that relates to the aesthetics, interface design, and content elements' design (in particular, the map design) with the visual design of the EA. It was the large number of IFs related to visual variables and design (i.e., IFs that have an indirect influence on the thematic content of the EA) that convinced us to make an exception and keep this group of IFs (see *rule 3*). Furthermore, visual design is included neither in the structural elements of the EA nor in the content elements of the EA *[1]* and can be considered a generalizing notion, for example, along with the design of the EA content.

The group is formed by IFs of two classes: *Layout* and *Visual Variable*. The purpose of the IFs of the Layout class is to select the layout of the EA and to manipulate the EA interface elements as components of the EA layout. The presence of this class of IFs was an argument for us to put this group of IFs second since the user can continue to customize the workspace and has not yet moved on to explore the content of the EA. Visual variables (also called graphic variables) were selected according to J. Bertin *[15]*. Location, size, texture, color, orientation, and shape have been complemented by transparency. Transparency is one of the five visual variables *[16]* that have been added to the seven variables of J. Bertin in cartography over the past decades.

The *Changing the Location of the Information and Navigation Structure's Element function* denotes the ability to move an element in the space of a window with a list of EA content elements, as a rule, of a network structure (there is no semantic load of this change). The adjustment of color value, as well as other color characteristics *[16]*, is possible using modern interactive tools along with color hue (color) adjustment. Hence, we have not allocated additional genera of IFs. The genus of the *Shape functions* for subgenera of the *Font functions* and *Label functions* denotes the typeface and style of the font. Since the typeface cannot be considered a separate visual variable, the corresponding subgenera of IFs are attributed to the shape as the closest visual variable in meaning to the typeface. The *Changing the Color Scheme of the Thematic Layer function* means that we can both change the color of an individual class of the map indicator and select the color scheme for all classes of the indicator.

Navigation

The IFs that provide access to the thematic content of the EA as well as the movement in the spatial and temporal dimensions of the EA and its elements. In our context, thematic navigation is about

how user access to the EA content elements is organized. It is provided by the information and navigation structure of the EA. By movement in space, we mean changing the user's viewpoint of the EA representation (change of the camera position) or movement in the EA content elements (primarily spatial models), which can be expressed by the X, Y, Z coordinates. Note that dragging objects is not related to navigation. Time navigation implies the ability to change the time attributes of the EA content elements and is often associated with such a dynamic data visualization method as animation. Thus, three subtypes of the navigation IFs were allocated: thematic navigation *(Content)*, spatial navigation *(Space)*, and time navigation *(Time)*.

The *Content subtype* is formed by IFs of the *Activation/Deactivation* and *Selection from* a List classes. The meaning of thematic navigation's IFs is precisely in those actions. The value of IFs of this subtype lies in the fact that each IF emphasizes the presence of a concrete content element or the very possibility of selecting a particular substantive content of the content element, its interpretation. For example, if there is no *Selection of the Thematic Map (Layer) Type function*, then there is no possibility to change the map (layer) type in the EA, which means that the interactivity and functionality of such an EA will be lower. We do not include search IFs and related sorting and filtering operations as thematic navigation. These actions already involve a targeted exploration of the subject area of the EA or the use of GIS functions (by origin) and are more appropriate for the next group of IFs. The *Activation/Deactivation of the Visualization Window function* provides that several content elements can be opened simultaneously in the EA visualization block and denotes the concrete window of the visualization block in which the selected content element should open. The *Selection of the Information Architecture of the Content function* enables the user to switch between different modes of organizing EA content (e.g., content tree, matrix, network, mixed, etc.).

In the *Space subtype*, the IFs are distributed among the *Zooming*, *Movement*, and *Centering classes*. We associate the differences between classes with a change in the Z coordinate; coordinates X or Y or X, Y (apart from IFs with a 3D dimension, for example, *Map Rotation*); and pairs of coordinates X, Y or X, Y, Z, respectively. The genus differences of the *Zooming class* lie in the way of zooming. Therefore, the allocated IFs are actually interactive tools and "raised" to IFs due to their special importance for the cartographic systems (CS). The ability to zoom is not limited to maps, but extends to information and navigation structure and graphics. In such cases, this operation is called geometric zoom or semantic zoom. The latter means that each zoom level corresponds to the representation of objects with a different degree of detail (an analogue of cartographic generalization). Recall that how the IF is implemented is a matter of functionality, not interactivity. Thus, geometric or semantic zooming here will be done using the same IF. The *Movement class* contains IFs of changing the viewpoint of the EA representation. We draw attention to the *Panning in the Information and Navigation Structure function*, which implies that the information architecture of the EA content is organized, for example, in the form of a network that can be navigated by panning. The IFs of the last class correspond to different methods of centering (which, as a rule, also includes zooming) on the map object of the EA. For example, the *Centering on the Map Object Using Data Table function* sets the viewpoint of the representation on the map object selected by the user in the data table of the thematic layer/map.

The Time subtype is represented by one class of IFs—*Setting*. The IFs of this class enable us to select a date or time period of data to visualize in a table or on a map. Also, the time navigation IFs are designed to manage animation and content elements where there are time variables. The Setting the Animation Interval function denotes the change of the time interval of each animation step within a specified time period.

Analysis

The IFs that provide a detailed examination of the EA content elements in order to gain knowledge or obtain additional information about the topic (story) and the modeled objects and phenomena, their spatial relationships and patterns. We interpret the analysis in a general sense *[17]* and do not identify it only with GIS functions of analysis and modeling, as well as statistical and mathematical methods, which, of course, are also included in this group of IFs.

The analysis IFs are allocated among seven classes: *Sorting*, *Filtering*, *Query*, *Selection*, *Construction*, *Calculation*, *Modification*. The IFs of the *Sort class* perform the simplest analytical operation—ordering the entire set of elements according to the selected criterion. The *Filtering functions* already enable us to select elements of a set according to selected criteria and more sophisticated methods, in particular, using SQL expressions. The genus of IFs *Filtering by*

Keyword is actually the *Search functions*. As a rule, search, which forms a list of elements according to criteria, and filtering, which excludes elements from the list according to criteria, are accepted to distinguish. However, both operations require the setting of criteria and show the result of dividing the whole (set of elements) into parts (certain elements of the set), and therefore can be considered analytical functions and functions that filter information about the subject area. After finding the needed objects and performing visual analysis, the user typically applies IFs of the *Query class*, which enables obtaining additional information about the EA content elements and their individual components. The next *Selection class* contains the IF of selecting or adding to the selection certain objects of the EA content elements for the purpose of further operations on them. It is noteworthy that this selection is accompanied visually, usually by flashing or highlighting. The *Construction class* is composed of graphical analysis IFs. The last two classes of IFs, *Calculation* and *Modification*, involve the application of mathematical and statistical methods.

The genus of the *Manual Sorting functions* enables the user to arbitrarily change the order of layers or EA content elements in the corresponding lists. The *Filtering by Attribute functions* may include selecting attributes from a list, entering them manually, or setting criteria for permissible values (range of values) for these attributes. It should be noted that all other genera of IFs of the *Filtering class*, except for *Filtering Content Elements by Map Extent* and *Filtering Using the SQL Expression in the Data Table*, in the strict sense, also refer to attributes. However, their allocation is important for such operands as the information and navigation structure, where the criteria for filtering, as a rule, are few and we can select the most essential. Therefore, the *Filtering by Attribute genus* refers only to data tables, where the number and content of attributes can be any. The *Filtering by Hierarchical Level in the Information and Navigation Structure function* enables us to display in the EA content tree only those elements that belong to the headings of a certain level (section, subsection, etc.). The idea of the *Filtering by Indicator Value of the Thematic Layer function* is to visualize (highlight) on the map only those areas that correspond to the us-

er-defined value interval of the mapping indicator. The *Filtering Content Elements by Map Extent function* denotes the filtering mode in which only those content elements that correspond to the territory of the current map extent are displayed in the information and navigation structure of the EA.

The *Query class* contains IFs, the purpose of which is to provide information about the selected element of the EA or its components. All IFs, except for *Getting Information About the Content Element*, are aimed at the map objects of the EA. A notable feature of the IFs of this class is that the user is only required to specify a point on the map. The *Selection of the Map Symbol in the Legend function* implies the selection (in particular, multiple) of concrete map symbols in the legend for visualization (highlighting) on the map. The construction of the hypsographic curve and the terrain profile are separate because they have a significant difference. In the first, the X-axis shows the area occupied by certain elevation and depth levels, while in the second, the X-axis indicates the length of the line on the terrain. It is remarkable that the profile can also show the structure of the object along the profile line, but this is already one of the implementation options of this IF. The *Chart Construction function*, also known as *Link the Data to the Chart*, provides that the selected records in the table will be used to construct a chart of the selected type or visualization of this data will be added to an existing chart. The first four IFs of the *Calculation class* include first graphical construction and then mathematical operations. IFs of the *Calculation of Data Statistics genus* can be applied both to the data table and to the thematic layer. For the table, it is a variety of mathematical and statistical operations on the selected records, and the second kind of the IF is designed to show the statistics of the particular mapping indicator (usually through the legend window). This information will be helpful for using the IFs of the last class of the group—*Modification*. The IFs of this class provide the user with the tools to classify the data of the thematic layer (changing the classification method, the number of classes, and class intervals). Moreover, modification is understood here not only as a selection from a list but also as the possibility for the user to specify all the variables himself.

Extensibility

The IFs that extend or correct the thematic content of the EA. After exploring the thematic content of the EA, the user may want to complement the content with their own materials or correct

the existing ones. Four classes of IFs are allocated for this purpose: *Renaming*, *Import*, *Addition*, and *Creation*. Thematic content correction is covered by the *Renaming class*. The following three classes of

IFs denote different variants of extensibility of the EA content by the user. Thus, IFs of the *Import class* refer to elements downloadable into the EA from the outside. In contrast, the IFs of the *Addition* and *Creation classes*, the line between which is quite thin, denote the addition or creation of elements directly by EA tools in the EA environment. Addition implies that a certain set of elements already exists, and new elements complement (keyword) it. For IFs of the *Creation class*, the key is the fact of creation from nothing, and connections to existing elements of the same type are secondary. Therefore, the *Adding the Attribute to the Data Table function* is the IF of the *Addition class*, and the *Creation of the Record in the Data Table function* is the IF of the *Creation class*.

Here we proceed from the fact that each entity already has a certain set of attributes, and we complement this set. In contrast, each record provides information about a separate object, and therefore the presence of other records can be ignored.

The *Adding the Visualization Window function* adds an additional window(s) to the EA visualization block (often this IF denotes multiple map view mode). The IFs of the *Creation of the Group genus* enable us to combine the EA content elements or thematic layers of the map into arbitrary groups. In the first case, this is done in order to quickly access the needed elements, and in the second, this IF will be useful for maps with a large number of thematic layers.

Recoverability

The IFs that cancel any changes by returning to the previous or original representation of the EA. The user, after making changes to the EA, should be able to cancel these changes, which are expressed by the IFs of such classes as *Disbandment*, *Resetting*, *Clearing*, and *Deletion*.

The IFs of the *Disbandment class* denote that some elements of the EA will no longer be combined but will not be deleted either. The IFs of the *Resetting class* set the representation of the EA or its certain elements by default, canceling all changes in these elements. The IFs of this class are divided into two genera of IFs because setting the representation of the EA or information and navigation structure by default does not imply the cancellation of changes made by the user in the content elements of the EA or information and navigation structure. We are only talking about opening the start page of the EA or the first level of the EA content tree, which is associated with the well-known *Home function*.

For IFs of the *Resetting Changes genus*, such map elements as legend and scale are allocated since it is often necessary to cancel changes only to some map elements. The *Clearing class* with the *Favourites* and *Selection genera* denotes the exclusion of all elements from the list or multiple deletion. In contrast, the IFs of the *Deletion class* enable us to delete concrete elements, in particular, those created using the *Addition/Creation functions*. Note that an IF that would only cancel the previous user action is not enough. Therefore, those important elements of the EA are allocated, the deletion of which should be possible at any time. The popular *Undo function*, which cancels the previous action, we consider a component of the *View Session History function* from the following group, which involves moving between EA representations both backward (undo) and forward (redo). That is, the key here is not so much the cancellation of user actions as the figuring out of their sequence.

Saving and Tracking

The IFs that enable users to save, share, and track the results of using the EA. The last of the hypothetical stages of using the EA implies that the user saves or shares the results obtained. The exploration of the EA is always a unique journey and a unique experience. That's why this group of IFs, in addition to the *Export class*, includes the *View class*, the IFs of which track the "user's path," that is, they record all user actions.

The *View class* consists only of the *View Session History function*. Moving between EA representations backward and forward is the simplest implementation of this IF. A more sophisticated modification of the *View Session History function* enables

us to review the entire list of user actions (all representation changes) and select any representation. The *Export class* contains IFs that provide for saving or sharing the representation of the EA or its elements in a certain way. The IF of the *Atlas kind* of the *Export File genus* denotes saving the current EA representation with all changes as a file, which can then be downloaded into the EA (with the ability to restore the EA representation) using the *Import the Atlas Representation function* from the *Extensibility group*. The *Share the Link to the Map function* also means that the map can be embedded in external web pages. The IFs of the *Image genus* make it possible to save the rep-

resentation of maps or graphs as images and take a screenshot of the EA representation. The *Print the Map function* is singled out because it implies printing the map with all layout elements (in particular, the legend) for demonstration in paper form.

Conclusions

The article summarizes the results of the project to create the classification of IFs of the EA, which consisted of two stages: the development of the theoretical and methodological basis of the classification *[1]* and its refinement, along with the direct creation of the classification. The full version of the classification is published at the link: https://bit.ly/3Ck3jvK.

The proposed classification is artificial and taxonomic with the combined structure: faceted radial at the first level and sequential within each facet (group). The main (type, class, genus, kind) and transitional (subtype, subgenus) taxonomic categories were allocated, the purpose of which is to emphasize the subordination of the classification groups of objects and to reveal the vertical connections between them. A total of one hundred and eighty-one IFs and seven groups of IFs (Settings and Support, Visual Design Adaptation, Navigation, Analysis, Extensibility, Recoverability, Saving and Tracking) are allocated, where each group corresponds to one of the features by purpose. The system of features is formed taking into account the hypothetical stages of the user's work with the EA: familiarization and customization of the EA workspace; search for needed content elements (information); manipulation of content elements (analysis, editing, addition); saving and sharing the results of work with the EA. The corresponding sequence of classification groups is conditional and is intended to ensure a better perception of the classification and work with it.

The classification is open to extension and modification. Among the IFs that have received insufficient attention and need to be complemented in the future are the IFs with 3D dimension and sound. Although the first EA with 3D terrain visualization appeared in 2000 (Atlas of Switzerland 1), 3D atlases are still not widespread and the list of IFs for them is still being formed. The majority of 3D functions are related to spatial navigation and are already included in the classification. Atlas cartography is especially indebted to cybercartographers for actively implementing IFs with sound *[18]*. However, after the presentation of the Cybercartographic Atlas of the Antarctic (2007), marked by a variety of sound IFs, even subsequent cybercartographic atlases have been limited mainly to voice IFs for didactic and descriptive purposes. In our opinion, the further development of the audiovisual component of the EA is one of the ways to restore the attractiveness of the EA for a wide range of users.

The novelty of the study lies in the creation of the classification of IFs of the EA that is based on the general theory of classification, takes into account and summarizes the experience of previous classifications of IFs, and is grounded in the results of a new analysis of the interactive capabilities of the EA. This is the first classification of IFs of the EA in Ukraine, which also sums up the experience of the last two decades of electronic atlas mapping in the country. The classification developed is the first step toward developing a mechanism for evaluating EA interactivity and, later, EA functionality.

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