

**КАРТОГРАФІЯ,
ГЕОІНФОРМАТИКА**

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**INTERACTIVE MAPS OF POTENTIALLY DANGEROUS OBJECTS OF UKRAINE:
PROBLEMS OF DATABASE CONSTRUCTION AND VISUALIZATION**

This article uses the notion of extended cartographic interactivity, which was first discussed in [1]. There it is proposed to extend the interactivity that is understood in subject and classical cartographies as a complement to the representation by maps the spatial entities and phenomena of the real world. The extension is based on the understanding that modern reality is much more effectively modeled not by a separate map, but by a system organized in the epistemological hierarchy of spatial information systems (SpIS). Cartographic interactivity in this modeling is not a simple complement to representations, but the very important elements of the SpIS constituents. SpIS constituents are related to one or another stratum of knowledge in the hierarchy of SpIS. As a consequence, cartographic interactivity is an important element of the system map model (SMM), which is the core of the hierarchical SpIS system being created.

The theoretical part of this article first briefly discusses the notion of a map model (MM). After a short introduction to the issues of MM, its current state is fixed. Accordingly, it is stated that in practice there are currently conceptual and physical MM. This situation is problematic, since there are virtually no theoretical and logical MM in the SpIS creation. In the absence of theoretical MM, the practically used conceptual and physical MM are not optimal. And because of the absence of logical MM, conceptual and physical MM are poorly matched. Therefore, when creating new SpIS, developers are forced virtually every time to start development from scratch - to create all the necessary MM. In order to solve the problems of the absence of theoretical MM, the first approximation to a more economical and correct decision is made - a SMM based on the Conceptual Framework of the Relational Cartography is given. It is the construct that should fill the gap between the theory and practice of using the MM.

The practical part of the article shows how the first SMM approximation is used in the construction of interactive maps of potentially dangerous objects in Ukraine. The constructed maps will explain how to use the extended concept of cartographic interactivity and, thanks to the first approximation of SMM, allow you to determine the relation between the maps and the SpIS of the lower hierarchical strata. The results obtained allow us to outline the problems of database construction and visualization, which derive from the extended cartographic interactivity.

Keywords: *cartographic interactivity; map model; relational cartography; database construction and visualization; interactive maps of potentially dangerous objects in Ukraine.*

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ІНТЕРАКТИВНІ КАРТИ ПОТЕНЦІЙНО НЕБЕЗПЕЧНИХ ОБ'ЄКТІВ УКРАЇНИ: ПРОБЛЕМИ ФОРМУВАННЯ БАЗ ДАНИХ ТА ЇХ ВІЗУАЛІЗАЦІЇ

У цій статті використовується поняття розширеної картографічної інтерактивності, яку вперше розглянуто в [1]. Там запропоновано розширити інтерактивність, що розуміється у предметних і класичних картографіях як доповнення до представлення за допомогою карт просторових сутностей і явищ реального світу. Розширення базується на розумінні того, що сучасну реальність набагато ефективніше моделювати не окремою картою, а системою організованих у епістемологічну ієрархію просторових інформаційних систем (ПрІС). Картографічна інтерактивність у цьому моделюванні є не простими доповненнями до представлень, а дуже важливими елементами складових ПрІС. Складові ж ПрІС відносяться до тієї чи іншої страти знань в ієрархії ПрІС. Як наслідок, картографічна інтерактивність є важливим елементом системної моделі карти (СМК), яка є серцевиною створюваної системи ієрархічних ПрІС.

У теоретичній частині цієї роботи спочатку коротко розглядається поняття моделі карти (МК). Після невеликого вступу у проблематику МК фіксується її сучасний стан. Відповідно констатується, що на практиці на даний момент

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існують концептуальні й фізичні МК. Така ситуація є проблемною, оскільки у діяльності зі створення ПрІС практично відсутні теоретичні та логічні МК. Через відсутність теоретичних МК не є оптимальними практично використовувані концептуальні й фізичні МК. А через відсутність логічних МК концептуальні і фізичні МК слабо узгоджені між собою. Тому під час створення нових сучасних ПрІС розробники змушені фактично кожного разу розпочинати розробку з нуля – зі створення всіх потрібних МК. Щоб вирішити проблеми відсутності теоретичних МК виконано перше наближення до більш економного і правильного рішення – наведено СМК, що базується на Концептуальному каркасі Реляційної картографії і тому є конструктом, який має заповнити розрив між теорією і практикою використання МК.

У практичній частині роботи показано, як перше наближення СМК використовується при побудові інтерактивних карт потенційно небезпечних об'єктів України. Побудовані карти пояснюють, як використовувати розширене поняття картографічної інтерактивності і, завдяки відповідності першому наближенню СМК, дозволяють визначити відношення між картами і ПрІС нижніх ієрархічних страт. Отримані результати дозволяють окреслити проблеми формування баз даних та їх візуалізації, що витікають із розширеного поняття картографічної інтерактивності.

Ключові слова: картографічна інтерактивність; модель карти; реляційна картографія; формування і візуалізація баз даних; інтерактивні карти потенційно небезпечних об'єктів України.

Introduction

The article presents new results on extended cartographic interactivity, which was first proposed and substantiated in [1]. There, cartographic interactivity is extended to a stratified notion, the meaning of which varies depending on the stratum on which the interactivity is examined. In fact, it is about interactivity on a few strata of some stratified spatial information system (SpIS) or, otherwise, SpIS in some broader (or extended) sense (SpISb), if the specific structure of the SpIS is unknown. The main criterion for belonging the SpIS constituent to a particular stratum is the amount of knowledge that is used to model reality with their help.

Extended cartographic interactivity is an element of the stratified map model. This extended interactivity can be simplified so that it is consistent with the interactivity discussed in the works of R. Roth [2, 3, 4, 5] and his colleagues and graduate students [6], [7], [8], [9]. Simplification is to reduce the complexity of modeled actuality and modeling processes. The authors of the cited works de facto understand the map as the main research subject in cartography. This understanding actually postulates that actuality in a wide range of contexts can be adequately modeled by one map, so modeling processes must ensure that one final map is obtained. Cartographic interactivity is a complement to the map's ability to graphically represent actuality (reality in a given context).

However, in the current decade, phenomena modeled not by a single map, but by systems of several SpIS have grown enormously. The simplest example is to use the OpenStreetMap geo-platform (OSM - SpIS1) as part of a company site (SpIS2). Despite the simplicity of this example, in the context described, it is not about maps, but about two SpIS that include maps. These and other examples allow us to argue that the research subject of cartography has changed so that it is difficult to imagine the practical context, in which it is enough to explore only the map. Due to the actual change of the research subject, both the understanding of the individual elements of cartography and the understanding of cartography as a whole must be changed. In particular, understanding of the cartographic interactivity need to be changed also.

It should be noted that the changes described are objective. They are independent of the current definitions of cartography and map (<https://icaci.org/mission/>, accessed 2019-Aug-12), or of our understanding of these notions. It is now necessary to investigate relational spaces or spatial systems [10]. This situation is fundamentally different from the last century, when the research subject of cartography was largely theoretical and discussed mainly by scientists. For example, in the 1970s [11, p. 14] has explained the fallacy of understanding the cognition subject in cartography: “The opinion that recognizes geographical maps as the cognition subject of cartography is so widely and persistently spread in cartographic literature that it was accepted almost as official and unconditional. In this regard, the need for a philosophical category¹ was neglected, which could be penetrated into the theory of cartography only through the conceptual definition

¹ Space-time

of the true subject of its cognition". This philosophical category of space-time was represented by A. Aslanikashvili with the help of the notion of an ideal concrete space. The latter concept actually coincides with the notions of relational space and the spatial system [10]. Nowadays, the research subject of cartography has of practical importance, since it is necessary to create new modern cartographic products, which are now mostly spatial information systems (SpIS).

In this article, practical examples of dealing with potentially dangerous objects address the cartographic interactivity in the SpIS Operational and Application strata, which are among the lowest in the SpIS hierarchy. In this hierarchy of SpIS, extended cartographic interactivity should be considered. The article explains how the interactivity of the Operational stratum is related to the interactivity of the higher, the Application stratum. A significant result of the article is an explanation of the reasons for using the database hierarchy and visualization, including an extended cartographic hierarchy.

Main Materials

Problem and System map model

Cartographic interactivity and interactive maps are based on a map model (MM). At the same time, due to the development of modern carto- and geo-information technologies, the so-called datalogical capabilities of cartographic modeling are constantly increasing. We can state the emergence of models that are already so qualitatively different from map models that even other terms are used. A well-known example is the OpenStreetMap (OSM) geo-platform. In fact, this is a type of SpIS and its model is qualitatively different from the MM. Such models are sub-models of the more common System map model (SMM). The SMM is the colored part of the *Tabl. 1*. It was obtained using the Conceptual Framework (CoFr) of Relational Cartography [11]. When constructing a particular SpIS, it is necessary for both the SMM as a whole and for the individual components of the MM to obtain (to model) the systems themselves for a given subject domain (research subject). Higher strata systems are or often are called schemes. There are "horizontal" and "vertical" relations between the elements of SMM. The application of horizontal relations in practice is from left to right and is called transformation. The use of horizontal relations from right to left is called verification. In general, this is a methodology of subject (and classical) cartography. The application of vertical relations in practice from the bottom to up is called epistemology. Top-down - reduction. In general, this is a methodology of relational cartographies.

In the *Tabl. 1* the following abbreviations are used: D - Datalogics, Datalogical level, I - Infologics, Infological level, U - Usagelogs, Organizational level or Usage World, O - Operational stratum, A - Application stratum, C - Conceptual stratum, G - General stratum. The strata are in line with the shown echelons of users. The notions introduced are defined and researched in the monograph [12]. However, in this work, we intend to give an interpretation of the notions that is quite independent of the monograph results.

MM is discussed below. Here we explain only why MM in *Tabl. 1* is named System (SMM). SMM corresponds to the Conceptual Framework of Relational Cartography (CoFr RelCa [12]), which is valid for all known types of SpIS: electronic atlases (EA), atlas information systems (AtIS), carto- information systems (CIS) and geo-information systems (GIS). That is, the SMM structure of all these systems is shown in *Tabl. 1*. Such a structure is valid for the above types of SpIS in the broader (extended) sense (SpISb). In addition, the activity of creating any mapping information product is a systemic or activity system. Therefore, the developer or researcher deals with the SMM, even if the result of the activity to create an information product (for example, a map) should not be a system. The presence of SMM in these processes is not always or even ever conscious. We hope that our work will remove this problem and allow developers and researchers to better understand the notion. Note that:

1. Depending on which one of the four echelons we have selected, we are dealing with four (sub) map models (MM), which are also referred as:

$SMM = GMM + CMM + AMM + OMM$ (1), where GMM - General MM, CMM - Conceptual MM, AMM - Application MM, OMM - Operational MM.

2. The MM of each stratum / echelon consists of:

$XMM = DXMM + IXMM + UXMM$ (2), where $X = O, A, C, G$, and D, I, U are defined above.

The left part of the *Tabl. 1* shows the parts of the real world that are modeled by the relevant SMM elements.

Usually, in the real world, a system is first defined, which is then modeled by one or more elements of the SMM. The model is defined as a simplification of the system, built with the intended purpose. The model should be able to answer questions instead of the actual system (Bézivin and Gerbé, 2001). For example, the system of the abstract world is modeled with the help of SMM, although the correspondence of the real world system and the corresponding each-stratum model (in this case SMM) is not always such straightforward.

The right part of the *Tabl. 1* shows an organizational user system that is divided into four echelons. There is a clear correspondence between the MM of each stratum with a certain echelon of users. The echelons can be virtual. For example, in every real project artifacts of practical stratum of O, A, C are formed. The creators of these artifacts must obtain the necessary theoretical knowledge that is the artifacts of the General stratum. These artifacts are usually created by scientists or instructors. However, instructors rarely participate in real-world projects, although virtually always they are present.

Formulas (1) and (2) are not simple. For example, the “+” sign is not a simple addition sign, but denotes operations that result in the construction of a map of several components of the MM formula, if we want to get a complete MM. That’s why we call it “superposition” here. For Operational and Application strata, the “+” sign in formula (2) indicates at least one of four cartographic operations or combinations there of: concatenation, image construction, coordinate transformations, and additions [13]. In formula (1), the meaning of this sign is even further than the addition, since there are relations between the elements of the strata such as, for example, classification/instantiation or conformTo. The first relation usually specifies the relation between information objects of the same system, such as an object/class. The second relation specifies the model/metamodel relation [14]. In both cases, formula (1) shows some kind of “union” of constituent elements, which we also call a superposition. In general, formula (2) refers to the methodology of subject (and classical) cartography (although it must satisfy the requirements for levels of relational cartography), and formula (1) refers to the methodology of relational cartography. Also not simple are the constituent elements of formulas (1) and (2). This article describes examples that help you better understand these formulas.

To give an example of CMM, we used works [7], [8], [9], [1]. So, in *Tabl. 2* it is shown the CMM (blue color) of SMM. This table is the result of three works. First there was a table from [8, p. 124]. In the work [1], the correspondence of interactivity with [8] and with the Electronic version of the National Atlas of Ukraine (EINAU) [15] was added to this table. Finally, here is the correspondence of the above table to the SMM Conceptual stratum. This gives an example of formula (2) for $X = C$ (Conceptual stratum or Infrastructure echelon). So, for example, to get a complete CMM of a choropleth map, you need to have Datalogics (D), Infologics (I), and Usagelogics (U). That is, the choropleth map pattern consists not only of “representation” but also of “data” and “interactivity”. Choropleth CMM will be a union of descriptions of these elements.

Column “I” shows the so-called product design patterns of presentation (or product infological patterns), and the column “U.interactivity” shows product design patterns of interactivity (or product patterns of use). Given the dualism of the product-process should assume the existence and process design patterns. For work purposes, it is sufficient to take into account the simplified understanding that the product pattern describes the typical final product and the process pattern describes the typical process of obtaining the final product.

Product design patterns of representation are actually discussed in [16]. It describes 28 (product) design patterns such as, for example, Micromaps, Choropleth Maps, and Interactive Maps. We note that G. Peterson calls the patterns “compositional” and indicates separately that they are design patterns in the sense of a monograph [17]. The chapter on patterns in [16] follows the chapters that discuss color and typography templates. That is why these patterns are called composite.

The Interactive Maps pattern in [16] is included in the list of composite patterns. In our opinion, this contradicts the logic of including patterns in the list. Indeed, the description of patterns [16] shows that these are (product) design patterns of representation in terminology [8]. The description of the Interactive Maps pattern resonates with the description of other patterns. It is not a design pattern of presentation that follows from its description: “Interactive are digital maps either entirely created by the cartographer, or, more often, created as mash-ups on familiar basemaps such as OpenStreetMaps or Google Maps. Interactive maps provide a lot of spatial knowledge in a compact space compared to static or printed maps. From toggling layers, to popups on mouseover, to increased detail on zoom, these maps enable a truly engaging experience. Used as teaching tools, decision-making tools, or navigational tools, these maps also span all conceivable

Table 1.

System map model (SMM)

Abstract world	DGMM	IGMM	UGMM	Users of the General echelon
Abstract-physical world	DCMM	ICMM	UCMM	Users of the Infrastructure echelon
Abstract-physical world	DAMM	IAMM	UAMM	Users of the Application echelon
The physical world	DOMM	IOMM	UOMM	Users of the Operational echelon

Table 2.

The navigation menu of the prototype web mapping (product) pattern library, organizing available design patterns according to: “beginning”, “data”, “map elements”, “presentation”, “interactivity” (8; p. 124). “EINAU”, blue color and D, I, U added by us

D		I	U	
getting started	data	presentation	interactivity	EINAU
boilerplate	load data	tile basemap	pan	
page layout	save	vector basemap	zoom	
	export	choropleth	retrieve	
	map elements	proportional symbol	overlay toggle	
	graphicule	dot density	filter	
	legend	isoline / surface	arrange	
		flow	reexpress	
		cartogram	sequence	
		bivariate / multivariate	resymbolize	
		animation	reproject	
		graphics / chart	search	

Table 3

Concentrated view of the problems of the actual map model

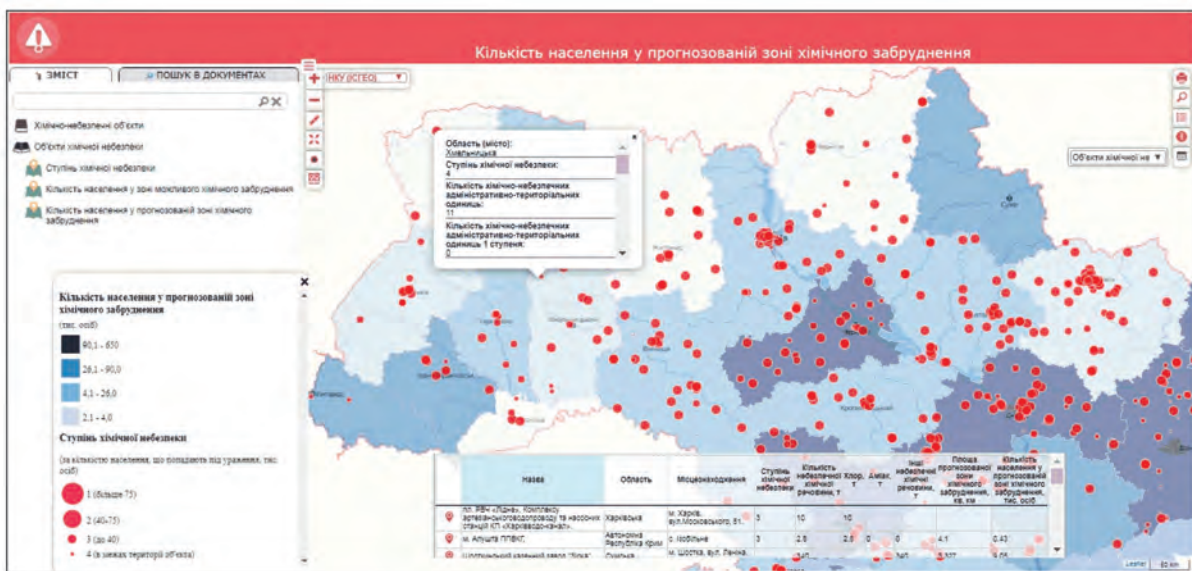
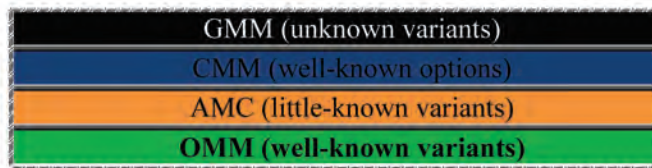


Fig. 4. Thematic map “Population in the predicted chemical contamination zone”

subjects with a spatial component”. However, the description given is an example of a design pattern, so we give it to the reader to have an impression of design patterns, no matter what the pattern is, representation, interactivity, or even data. We must also admit that we did not find in the compositional patterns of [16] the design pattern of presentation the “Proportional symbol” from *Tabl. 2*. That is, G. Peterson described not all design patterns of presentation.

Process design patterns of representation were discussed in the article [18], which “describes the approach of design patterns to conceptualizing the process of cartographic design. The design pattern presents a solution to the problem by describing commonalities in the problems to be solved. The commonalities of the cartographic design process are identified and MapDesign is described, a design pattern for generating a set of maps from big geospatial data”.

Now we can describe the problems of the map model from which the problems of cartographic interactivity follow. In concentrated form, they are presented in *Tabl. 3*.

We are unable to look at the well-known variants of the Conceptual and Operational MM in detail. We do not know the MM of these two strata that would be mutually agreed. There are individual Conceptual or Operational MM for which we know their agreed Application MM. For example, it is possible to find a Conceptual MM and (through experience) build an Application MM from the ArcGIS ecosystem. However, the ArcGIS Operational (physical) MM is closed, so it is unknown.

We do not know of any examples of the existence of all three agreed MM: Conceptual, Application and Operational. Rather, the MM of several strata contradict each other. For example, *Tabl. 2* shows the design pattern “Proportional symbol”, which is a Conceptual MM of this type. Below, we consider the physical implementation of the Proportional symbol map of actually the same authorship [7]. However, to see their consistency is very hard. We also do not know of any theoretical General map model (GMM) that would have practical implementation first as CMM and then as AMM and OMM.

Examples of Operational (physical) map model implementation. Methodology of subject cartography

This section uses examples of implementation of physical map models described in [7] and [9]. The content of each article is a guide or even a tutorial. The first article explains how to build a proportional symbol map using the Leaflet JavaScript library. The second article describes how to build a choropleth map using the D3 JavaScript library. The design patterns of both maps are included in the “presentation” column in *Tabl. 2*. In both articles, the methodology of subject cartography was used to construct maps. The content of the articles best fits the analytical or transformational paradigm of subject cartography. Only the types of maps and the details of the map-making processes differ. The methodology of the transformation paradigm of subject cartography in brief is shown in Fig. 1, which is a simplification [19, Vol. 1; fig. 2.8].

The example below illustrates how on the Operational stratum, on the one hand, transformation families from **Fig. 1** are applied, on the other hand, is superposition $OMM = DOMM + IOMM + UOMM$. Note that due to the use of the appropriate JavaScript library, we are not concerned with the cartographic operations of concatenation and image construction. We only perform cartographic operations of coordinate transformations and additions [13]. By the way, we note that we did not find continuation of the article [13] in the 21 century. Therefore, we argue that R. Ramirez’s theoretical MM is inconsistent with any actual Conceptual, Application, and Operational MM. That is, here we draw the reader’s attention only to the similarity of the constructions of the two theoretical and physical MM.

Both libraries, Leaflet and D3, allow you to build maps of both types, although these articles only describe “one library - one map” implementations. It is quite obvious that both libraries contain different physical MM. They are not defined obviously and are the realization of the ideas of the authors of the libraries. These models are empirical - they are implemented in libraries, but they are obviously not called that. Both articles describe the physical realization of T1-T5 transformations (**Fig. 1**). For CoFr RelCa, this is an Operational stratum. As the transformation articles differ in the two articles in detail only, let us focus on the adaptation to the Ukrainian data only of the article [7]. Next, we refer on this adapted guide as an AG.

Transformations T1, T2a, T2b were not performed. On the contrary, we used thematic data collected from public sources. Cartographic transformation of T3 is described in sections 1-4 of the AG. The result of the operations of section “1. Finding and Formatting Time Series Information” of AG is a city-data.json file in GeoJSON format (here is a time series by years: 2001, 2006, 2011, 2016):

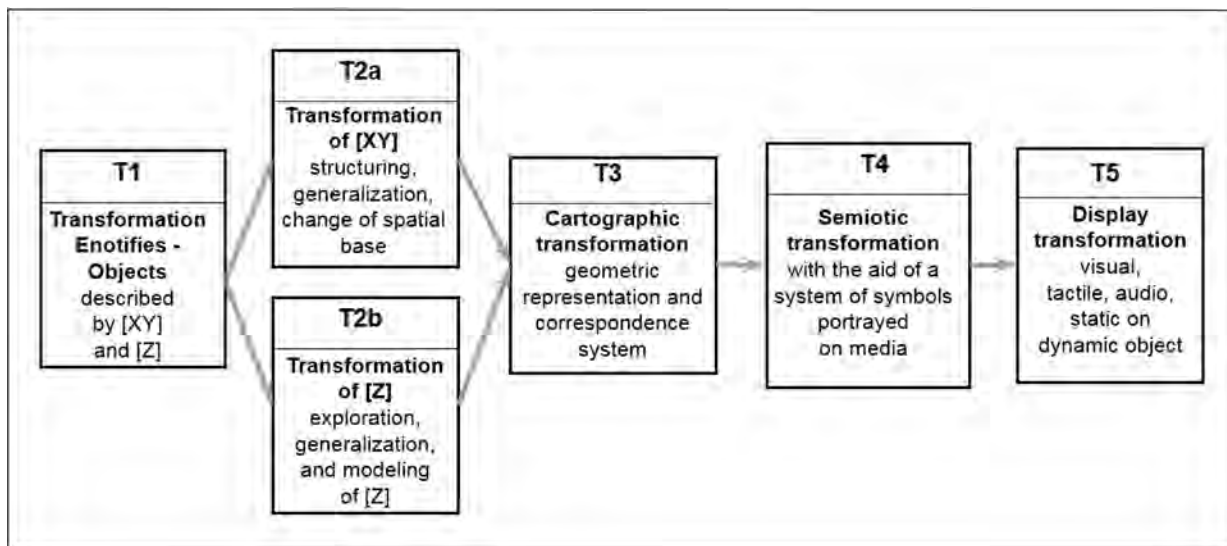


Fig. 1. Transformation families from [19, Vol. 1; fig. 2.8]

```

{ "type": "FeatureCollection", "features": [
  { "type": "Feature", "id": 1, "properties": { "id": 1, "name": "Luts'k", "lat":
50.736625, "lon": 25.383431, "2001": 62, "2006": 62, "2011": 75, "2016": 32 },
"geometry": { "type": "Point", "coordinates": [ 25.383431, 50.736625] } }
...

```

The specified file was obtained from a pre-prepared table of values of the number of potentially dangerous chemical objects by years:

ID	KOATUU	UkrName	RusName	EngName	lat	lon	2001	2006	2011	2016
1	0710100000	Луцьк	Луцк	Luts'k	25.383431	50.736625	50	36	18	11
2	6810100000	Хмельницький	Хмельницкий	Khmel'nyts'kyi	26.994747	49.413017	13	36	24	15
3	5610100000	Рівне	Ровно	Rivne	26.250290	50.611325	23	31	15	10
4	4610100000	Львів	Львов	L'viv	24.012400	49.829335	25	26	27	48

...

One of the results of section “2. Preparing a Directory Structure and Boilerplate” of AG is an index.html application start page layout:

```

<html lang="en">
<head>
<meta charset="utf-8">
<title>Leaflet Proportional Symbol Map </title>
  <meta name="viewport" content="width=device-width">
  <link rel="stylesheet" href="css/leaflet.css">
  <link rel="stylesheet" href="css/style.css">
</head>
<body>
  <div id="wrapper">
    <div id="map"></div>
  </div><!-- end wrapper -->
  <script src="js/jquery.js"></script>
  <script src="js/leaflet.js"></script>
  <script src="js/main.js"></script>
</body>
</html>

```


From this page is visible that it is the root directory, the map will be inserted into `<div id = "wrapper">...</div>`, and the directories are `js`, `css` and the directory `data` is not shown in the `index.html`. A single `city-data.json` data file is placed in the `data` directory. Other directories include the `main.js` application file and its style. `css`, `leaflet.css`, `jquery.js` are the files of external JavaScript Leaflet and jQuery libraries. This describes the complete application structure, called the "Leaflet Proportional Symbol Map".

The result of the operation "3. Loading a Basemap Using Leaflet" of AG is to display in the browser the image (without decoration) of the desired basemap (BM). The center of the map is located near Cherkasy city and has geographical coordinates (32.23, 49.13). OpenStreetMap (commented) and/or ISGeo tile servers are used. Code fragment from the `main.js` file:

```
var map = L.map('map', {
    center: [49.13, 32.23], // Україна, біля Черкас
    zoom: 4,
    minZoom: 6
});
L.tileLayer(
// 'http://{s}.tile.openstreetmap.org/{z}/{x}/{y}.png', {attribution: 'OpenStreetMap'}
'http://tileserver.isgeo.kiev.ua/{z}/{x}/{y}.png', {attribution: 'Національна карта ІСГео'}
).addTo(map);
```

The physical BM model is understood from the operator `'http://tileserver.isgeo.kiev.ua/ {z}/{x}/{y}.png'` or `'http://{s}.tile.openstreetmap.org/{z}/{x}/{y}.png'` and the information contained therein. Visually, this is a tile pyramid, which layers we see in the browser. The cartographic transformation of T3 on the Operational stratum is completed by executing section "4. Loading the GeoJSON" of AG. The download operation for the `city-data.json` file is shown in the `main.js` file fragment:

```
$.getJSON("data/city-data.json")
    .done(function(data) {
        var info = processData(data);
    })
    .fail(function() { alert("There has been a problem loading the data.");});
```

The result of the Cartographic transformation of T3 is a datalogical scheme of the proportional symbol map of the Operational stratum of the quantity of chemical objects. Now we can conclude on the essence of DOMM (Datalogical Operational MM), which is shown in *Tabl. 1*. For the proportional symbol (type) maps the DOMM consists of two models. The first model is a tile pyramid model and is used for the basemap image scheme shown as [XY] in *Fig. 1*. The second model is a GeoJSON format model and is used for the thematic data scheme shown as [Z] in *Fig. 1*.

For the tile pyramid model, the geographical projection reflects the Earth at a rectangle 360 degrees wide and 180 degrees high [20]. This projection has a natural 2-to-1 aspect ratio. For each subsequent level, the number of rows and columns is doubled. As each dimension doubles, the number of tiles at each subsequent level is 4 times greater than the previous one. When zoomed in by one zoom, each tile is replaced by four sub-tiles. This process can be continued to the required number of levels. In practice, 20 levels are sufficient for all available Earth cartographic data. Equations (DOBM.01), (DOBM.02) define respectively the number of columns and rows for level i .

$$C_i = 2^i \quad (\text{DOBM.01})$$

$$R_i = 2^{i-1} \quad (\text{DOBM.02})$$

For level $i = 5$ $R_5 = 16$, $C_5 = 32$. *Fig. 2* shows that at this level Ukraine is represented by six tiles 256x256 pixels in columns 17-19 and rows 10-11. Kyiv (КІІВ) city is at tile (R_{10} , C_{18}). It can be obtained at `http://tileserver.isgeo.kiev.ua/5/18/10.png`, accessed 2019-Aug-21. This tile is a superposition of the image (Datalogics) and its color representation for part of the state border and the caption КІІВ (Kyiv, Infologics). We hereby demonstrate that such a BM is also characterized by the selection of Datalogics, Infologics and Usagelogs.

Equations (DOBM.03) - (DOBM.06) bind a tile address to a geographic (geodetic) bounding box.

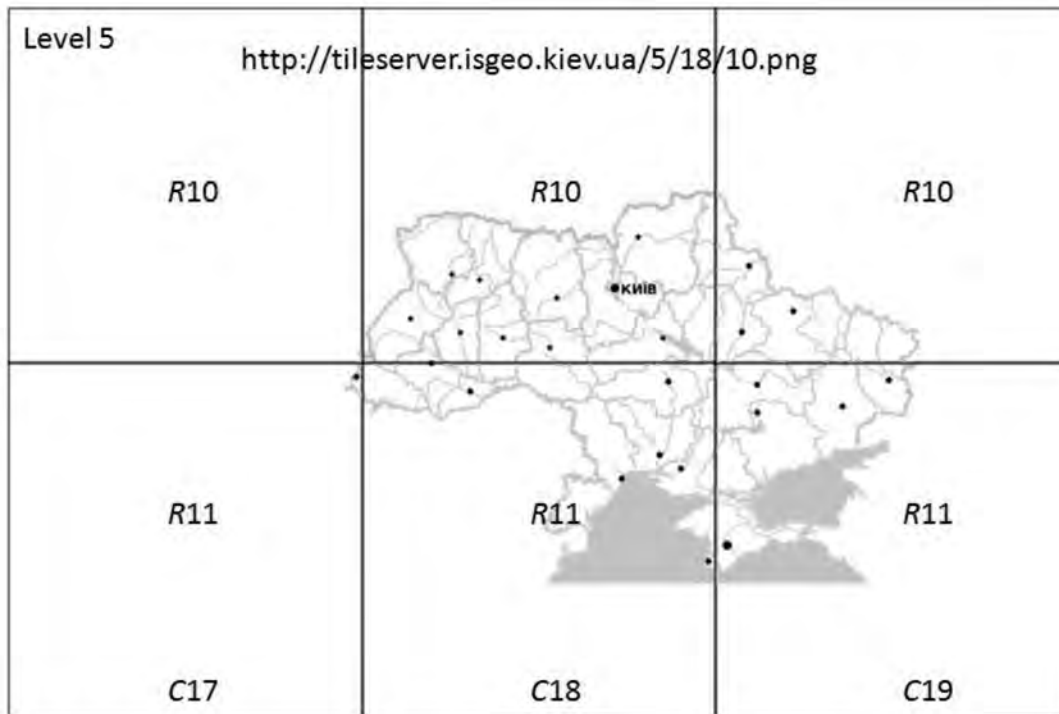


Fig. 2. Level 5 for the Ukraine image on the example of the ISGeo tile server

$$\lambda_{\min} = c * (360.0/2^i) - 180.0 \quad (\text{DOBM.03})$$

$$\lambda_{\max} = (c+1) * (360.0/2^i) - 180.0 \quad (\text{DOBM.04})$$

$$\varphi_{\min} = r * (180.0/2^{i-1}) - 90.0 \quad (\text{DOBM.05})$$

$$\varphi_{\max} = (r+1) * (180.0/2^{i-1}) - 90.0 \quad (\text{DOBM.06})$$

where c - column, r - row, λ - longitude, φ - latitude, and i - zoom (zoom level).

Equations (DOBM.07), (DOBM.08) show the location method of a tile containing specific geographical coordinates at a given zoom level.

$$c = \lfloor (\lambda + 180.0) * 360.0 / 2^i \rfloor \quad (\text{DOBM.07})$$

$$r = \lfloor (\varphi + 90.0) * 180.0 / 2^{i-1} \rfloor \quad (\text{DOBM.08})$$

where c - column (horizontal tile index), r - row (vertical tile index), λ - longitude, φ - latitude, i - zoom level, $\lfloor \dots \rfloor$ - integer part ("floor") of the number.

An up-to-date original description of "The GeoJSON Format" is available at (accessed 2019-Aug-17) <https://tools.ietf.org/html/rfc7946>. GeoJSON is a format for representing different geographic data structures. A GeoJSON object is represented by geometry, feature or feature collection. GeoJSON supports the following types of geometry: Point, LineString, Polygon, MultiPoint, MultiLineString, MultiPolygon, and GeometryCollection. A feature in GeoJSON consists of geometry and additional properties, a feature collection is a feature set. In GeoJSON, there is a hierarchy of kind GeoJSON Object => feature collection => feature => geometry. In GeoJSON, an object consists of a set of key/value pairs, also called properties. The name of each property is a string. A property value can be a string, a number, an object, an array, or one of the "true", "false" and "null" literals. An array consists of elements where each element can take one of the values described above.

We cannot further consider the Semiotic transformation T4 and the Display transformation T5. So here are some important points to make:

1. Transformations T4 and T5 are implemented in the same main.js code. This implementation is contained after the T3 implementation described above. That is, the superposition is from left to right.

2. The result of T4 is the infological scheme on IOMM. That is, the T4 transformation implements the transformation of the DOMM into a map representation. Namely:

- Section "5. Processing the GeoJSON" of AG describes a procedure that allows you to find the minimum and maximum values in time series.

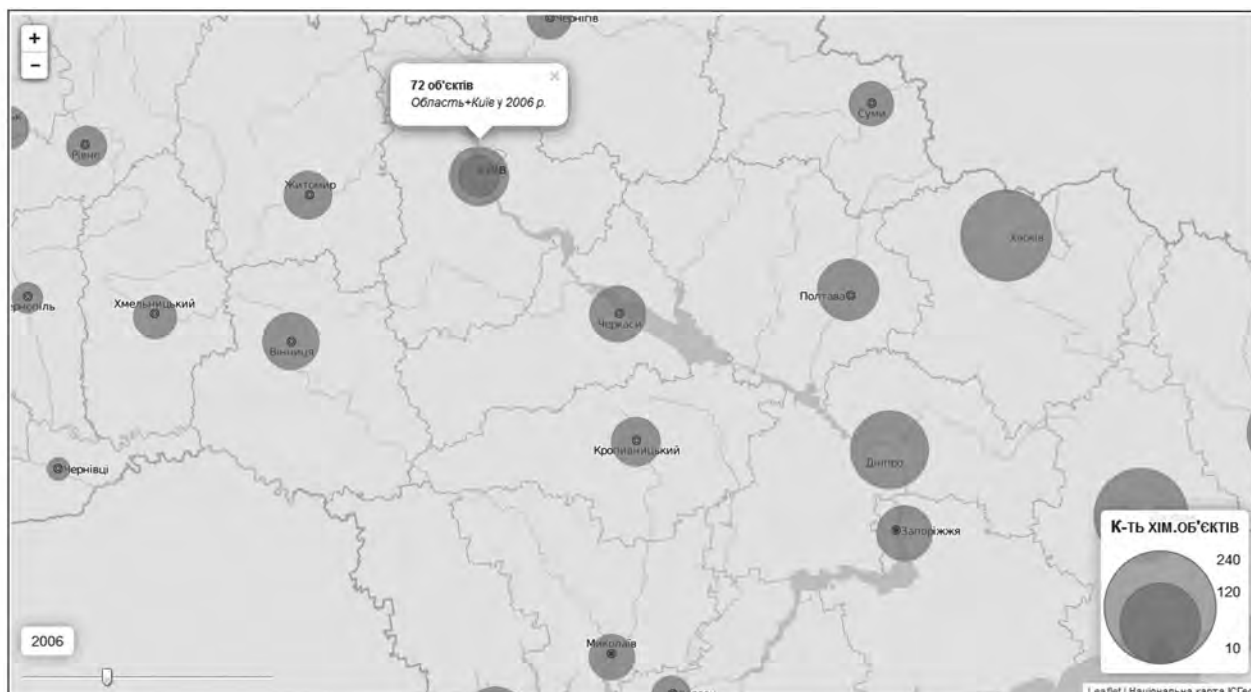


Fig. 3. Leaflet Proportional Symbol Map for Quantity of Chemical Objects

- Section “6. Drawing the Proportional Symbols” of AG describes the procedure for drawing with the help of Leaflet colored circles in SVG format.

- In the section “7. Scaling the Proportional Symbols” of AG the minimum and maximum time series values are used to scale circles.

- In the section “8. Creating a Map Legend” of AG is formed the picture explaining the value of the circles formed in chapters 5-7.

- We do not formally describe the models of circles and their images in the form of a legend, as we understand what IOMM is and what IOMM scheme is about in this example.

3. The result of T5 is the scheme of use on UOMM from *Tabl. 1*. That is, the T5 transformation implements the transformation of IOMM into cartographically interactive. These are two sections: “9. Adding a Temporal Slider” and “10. Creating a Temporal Legend”. Again, let’s not go into further detail, but note that interactivity is both on the thematic layer and on the BM layer. On the BM layer it is the Zoom-in/Zoom-out – the component, which can be displayed/no-displayed with the control by Leaflet.

4. The resulting map of the Operational stratum is a superposition of the schemes of DOMM, IOMM, UOMM. The result of the superposition is shown in the “Leaflet Proportional Symbol Map” for “Q-ty (Quantity) of Chemical Objects” (К-ТЬ ХІМ. ОБ'ЄКТІВ) in **Fig. 3**.

Examples of Operational (physical) and Application (logical) map models implementation. Methodology of relational cartography

AtlasSF1.0(3) Solutions Framework (SoFr) used to obtain the results of this section was obtained in 2014. That is, at about the same time as the above-mentioned results from the University of Wisconsin-Madison scientists. Please note that scientists at the University of Wisconsin-Madison have decided to provide the right education to cartographers at US universities. We had the task of releasing a practically useful Emergency Situations Atlas of Ukraine (AtlasES) in 2014. According to the conception of AtlasES (Rudenko et al., 2010), it was planned to produce the AtlasES of classical type using AtlasSF1.0(2) technology and, if possible, to release the AtlasES of geo-mashup type. Quite early during the implementation of the AtlasES project (sometime in 2012), two unpleasant things came to light: 1) AtlasSF1.0(2) technology had become obsolete at the time of AtlasES release (in 2014) and 2) funds for the development of AtlasES technology geo-mashup type will not.

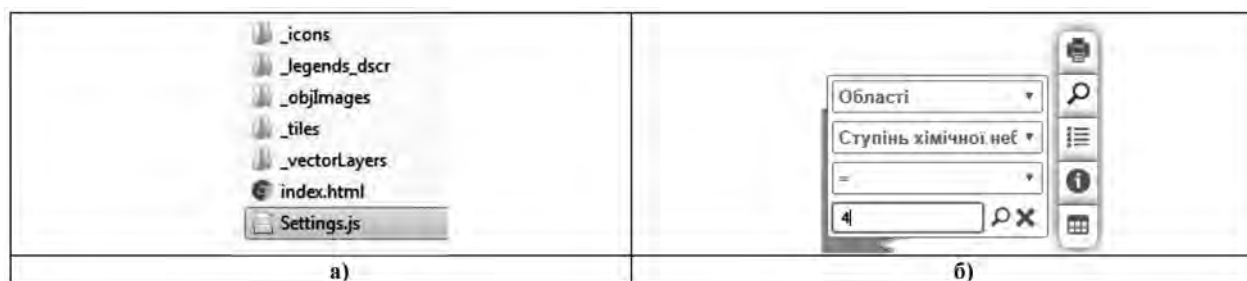


Fig. 5: a) Structure of the catalogs of the map "Population in the predicted chemical contamination zone", b) Interactive function "Search by condition"

In this situation, AtlasSF1.0(3) technology was developed, which is AtlasSF1.0(2) refactoring. That is, the technology has not been reengineered. Only the features that were supposed to be problematic in 2014 were rewritten. It should be noted here that AtlasSF1.0 is a SoFr that allows not just maps but EA and AtIS to be made of the classic type.

With AtlasSF1.0(3) we produced AtlasES in 2014 and later several other products. One of these products is "Interactive Map 'Ukraine. Chemical-Dangerous Objects (2017)'. Consider building a thematic map "Population in the predicted chemical contamination zone" for this article (*Fig. 4*). The map contains two thematic layers that characterize the chemical dangerous by area (choropleth map) and by potential chemical danger (proportional symbol). One of the two tables - Chemical Dangerous Objects - is shown on the map below. In addition, data about a particular object can be obtained from the so-called "Pop-up" menu.

The indicated thematic map is constructed by successive transformations from *Fig. 1*. It is then plugged into the final product (along with other maps) as an independent item. However, when using SoFr AtlasSF1.0(3), there is a significant difference from the solution described in the previous section. Namely, in addition to the `index.html` map start page, the `Settings.js` file appeared in the root directory. The structure of the AtlasSF1.0(3) map directories is shown in *Fig. 5a*.

The `Settings.js` file is a very important difference, even with the change of methodology of map construction from subject to relational. Indeed, in the example in the previous section, the map creator developed the map on the Operation stratum, except for the basemap. He implemented in the `main.js` code a specific physical map scheme. To create another scheme, the map creator had to be proficient in programming. That is, instead of creating the map itself (Infologics), the creator should be concerned with the code (Datalogics). The `Settings.js` file describes the map, but already for the Application stratum, which is epistemologically higher than the Operational stratum. As will be shown below, the map creator should now be concerned with creating the map itself, not its code.

The Datalogical map sub-model almost coincides with the same description in the previous section. Only the data file was slightly modified. For example, the beginning of a `ThemMap1_01.js` data file looks like this:

```
var ThemMap1_01 = {"type": "FeatureCollection", "crs": { "type": "name", "properties":
{ "name": "urn:ogc:def:crs:OGC:1.3:CRS84" } }
```

Thematic data is presented in GeoJSON format, but it is now "wrapped" with the name of the `ThemMap1_01` layer. Files `*.js` can be placed in the `_vectorLayers` map directory. However, for large atlases there are two problems: the amount of data to display a single map and the number of layers and atlas maps. Database Management System (DBMS) is used to solve both problems. We use two types of DBMSs: relational and so-called no-SQL DBMS. No-SQL DBMS are used when you can create your own JavaScript based infrastructure. This is usually the MongoDB DBMS. When dealing with mixed infrastructures, the PostgreSQL/PostGIS relational DBMS is also used.

For the map application, the `Settings.js` file is a configuration file that sets out how the individual fragments of the map scheme that are responsible for the data (Datalogics), presentation (Infologics) and interactivity (Usagelogics) of the map will be combined. The following is a list of features and sample descriptions for the

fragments of Settings.js:

- Zoom and coordinates of the default center for the map as a whole.
- Links to legend files and map descriptions.
- Order of loading map layers. The layers will be loaded in the order they are listed in Settings.js.
- Base layers to be used.
- Name of an individual layer.
- Initial zoom, the range of possible zooms for a single layer.
- Interactive features “Get Map Info” (bindPopup), “Search by Condition” (FindProperties), “Data Table”

(localizedProperties).

Let’s take a closer look at the interactive features in the example of ThemMap1_01 layer, which in Settings.js is given by the following line:

```
new L.geoJson(ThemMap1_01, {BaseName: "Області",
```


The interactive feature “Get information about a map object” is implemented in the bindPopup section:

```
bindPopup(this.getPopupContent(feature, {"Stupin": "Ступінь хімічної небезпеки", "Num":  
"Кількість хімічно-небезпечних адм.-тер. одиниць"}))
```

For example, information from ThemMap1_01.js on Stupin, Num, etc. attributes will be displayed for the oblast. By following the rules in this section, the user can get information about the object from the map by clicking on it. A window of information appears in our example to inform about the Khmelnytsky oblast. The 4th degree of chemical danger has been established. The oblast has 11 chemical-dangerous administrative-territorial units, etc.


The “Search by Condition” interactive feature is implemented in the FindProperties section.

```
FindProperties: [{"propName": "OblName", "descr": "Область (місто)", "type": "1"},  
{"propName": "Stupin", "descr": "Ступінь хімічної небезпеки", "type": "3"}],
```

The function is activated through the button  “Search by condition” (**Fig. 5b**). In the search box, you must specify (by selecting from the drop-down list) the name of the layer, the name of the indicator and the condition under which the search is performed. In our example, we look for all oblasts where the chemical danger is 4. The oblasts found will be highlighted on the map.

The “Data Table” interactive feature is implemented in the localizedProperties section:

```
localizedProperties: "OblName": "Область (місто)", "Stupin": "Ступінь хімічної небезпеки", ...}
```

The given table is activated for viewing through the button  “Data table” (**Fig. 5b**). In the list of available layers, select a name. In the example in **Fig. 4** you can see that the chemical danger table (ThemMap1_02.js) is selected, the data table is displayed at the bottom in the map window. The number and name of columns in the data table meets the specified conditions in the localizedProperties section.

Below are the modules that are responsible for the cartographic representation for thematic layers. For area objects – oblasts (data from ThemMap1_01.js) - we use a choropleth background mode. The danger assessment is based on the indicator “Population in the predicted chemical contamination zone, thousand people” (Popul5 attribute). The scale is reduced by 4 gradations from light tone for areas where the potential danger is lower, to a more saturated tone for potentially dangerous areas (see **Fig. 4**):

```
onEachFeature: function (feature, layer) {var lColor = "";  
if (feature.properties.Popul5 >= 0 && feature.properties.Popul5 <= 0.1) {lColor = "#f0f0f0";...  
layer.setStyle({"opacity": 0.7, "fillOpacity": 0.5, "color": "white", "fillColor": lColor, "weight": 1})
```

For point objects (ThemMap1_02.js), we use the proportional symbol method. The radius of the circle that indicates the location of the objects depends on the quantity of “Chemical danger (by the number of affected populations, thousand people)” (Stupin attribute) (see **Fig. 4**):


```
pieDataProperties: {"Stupin": "red"},
pointToLayer: function (feature, latlng, properties) {var radiusCircle = 0; if (feature.properties.Stupin
== 1)...
return L.pieChartMarker(latlng, feature, {outerRadius: radiusCircle,fillOpacity: 0.7,weight: 1, color:
"white",opacity: 1, pieDataProperties: properties.pieDataProperties, ...}}
```

The last line contains the settings for displaying proportional symbols such as punch radius, color and contour thickness, fill transparency, and more.

Finally, we note that this section describes the implementation of the OMM + AMM superposition, which relates to the methodology of relational cartography. Indeed, with the use of AtlasSF1.0(3) SoFr and, in particular, Settings.js, we now have the ability to work with not one map, but with a class of maps of the same kind, and therefore have more opportunities to deal with map Infologics rather than their Datalogics.

Conclusions

We hope that enough information is provided to support the following conclusions:

1. Cartographic interactivity is a Organizational (sub)model in a map model (MM) of some startum. For a specific stratum, MM is a superposition of three (sub)models: Datalogical, Infological, and Organizational. This superposition is shown in the article, at least, for the MM of Operational stratum.
2. There are four per-stratum MM: Operational, Application, Conceptual, General. These models are in epistemological/reduction relations with each other, forming the System map model (SMM) together.
3. Only the model itself is sufficient to create spatial information systems (SpIS) or maps lower than the MM of a particular stratum. However, to deal with large territorial (spatial) problems, you need to have and be able to work with complete SMM and with SpIS built with these SMM.
4. In the case of large SpIS such as the National Atlas, a SMM should be used. The resulting system must be the system of components of the SpIS of several or even all four of the above strata.
5. In the case of large SpIS, the use of databases is mandatory. The SMM specifies the possible structural organization of these databases. Each stratum system must have its own database. Databases of neighborhood strata should be in the epistemological/reduction relations.
6. Cartographic interactivity should be developed for the SpIS of each stratum. The cartographic interactivity of neighboring strata should be in the epistemological/reduction relations.

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