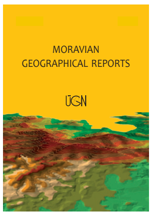

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Conceptualising patterns of spatial flows: Five decades of advances in the definition and use of functional regions

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Abstract

Some fifty years in the development of ideas about the definition and use of functional regions are elaborated in this article, as an introduction to this Special Issue of the Moravian Geographical Reports. The conceptual basis for functional regions is discussed, initially in relation to region-organising interactions and their behavioural foundations. This paper presents an approach to functional regions which presumes that such regions objectively exist and that they are based on more or less tangible processes (however, a different view of regions is also briefly described). A typology of functional regions is presented and the development of methods for finding a definition of functional regions is discussed, as well as a typology for these methods. The final part of this article stresses the importance of functional regions in geographical research, and introduces some emerging new prospects in the study of functional regions.

Key words: *spatial flows; functional region; functional regionalisation; regional taxonomy; geographical thought*

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1. Introduction

There is a long tradition in geographic research distinguishing between two basic types of regions: formal and functional regions (Robinson, 1953; Nystuen and Dacey, 1961; Haggett, 1965; Grigg, 1967; Abler et al., 1972; Symanski and Newman, 1973). These types differ in the character of their region-organising criteria: formal regions are based on scalar or vertical data; functional regions are based on vector or horizontal data (see Fig. 1). This division of data is based on their spatial characteristics. However, it should be noted that all geographical data have also their temporal dimension: they can be either instant (referring to one point in time, such as date of census) or periodical (recorded for a certain period). Apart from this division of data one should be aware that another role of time in geographical research regards the temporal evolution of geographic information.

Getting back to a spatial view of geographical data, scalar data are related to the concept of a site (Ullman, 1980), where importance is given to the vertical or static nature of this data, even though their distribution can vary over space. Very often this verticality is rather symbolic in human geography, where spatial distributions of various criteria overlay one another. In physical geography this verticality is more tangible: the character of the bedrock and the climate influence soil type, hydrological regime and the character of the vegetation at a particular site. In contrast vector data connect two sites, origin and destination, and thus are related to the concept of a situation (Ullman, 1980), where importance is given to the horizontal or movement nature of these data. These differences are mirrored in their distinct forms of spatial organisation and the inner structure of their respective types of regions. Papers in this Special Issue concentrate specifically on functional regions and functional regional taxonomy.

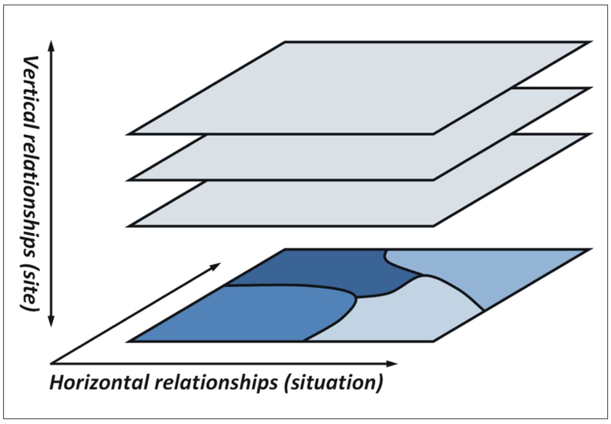

Fig. 1: Foundations of formal and functional regions
Source: Klapka et al. (2013a)

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In 1967 the proceedings of the 4th general meeting of the Commission on Methods of Economic Regionalisation of the International Geographical Union, held in Brno, Czechoslovakia (September 7–12, 1965), were published by the Czechoslovak Academy of Sciences as the book "Economic Regionalisation", and edited by Miroslav Macka (1967). The book includes chapters by renowned geographers such as Brian Berry, Torsten Hägerstrand, Kazimierz Dziewoński, Hans Bobek and others. Fifty years have passed and the issue of functional regions and their definition has experienced rapid development, particularly in the methods of delineation of functional regions. This Special Issue of the Moravian Geographical Reports resumes the topic of functional regionalisation raised five decades ago and revives its importance, particularly in Central Europe, taking into account current knowledge and developments in this field.

The significance of reviving interest in the issue of functional regions and methods for their delineation is in accord with what we call "the second quantitative turn" in human geography. Regions objectively exist in reality no matter if individual perceptions and aggregated individual perceptions can make the concept of region somewhat blurry, both in a spatial and a cognitive sense. In this respect, the strong assumption that the boundaries of regions can be identified in space is not irrelevant at all. This is not in opposition to views which see regions as more or less temporary social constructions (see for instance, Murphy, 1991; Taylor, 1991; Terlouw, 2001). Even in this respect, Paasi (1991) sees, as part of their social construction (Terlouw, 2001), four shapes of regions (territorial, symbolic, institutional and functional), some of them being closer to the concept of a region as an objectively existing reality.

Given that the objective existence of regions is accepted or taken for granted, it is only logical that objective methods for their identification and definition should be applied, and that the objective methods lean towards quantitative approaches. This does not mean that objective regions are eternal entities. Quantitative approaches certainly examine the appearance, evolution, pulsation and demise of regions in time, but they concentrate on more tangible foundations for their existence than postmodern approaches. It is the quantitative approach that is discussed further in this paper. After decades of challenging the objective virtues of regions and concentrating on their social construction foundations, inspired for instance by the works of Bhaskar (1998, first published in 1979) and Giddens (1984), the importance of quantitative approaches to the identification and definition of regions is once again being acknowledged (for general consideration and personal confession see Johnston, 2008; Haggett, 2008; for the field of regional taxonomy see e.g. Casado-Díaz and Coombes, 2011; Farmer and Fotheringham, 2011). The behavioural foundations of regions, however, as seen by Giddens (1984) for instance, are briefly discussed in the following section.

2. The essence of spatial flows and the context of human behaviours

The existence of horizontal spatial flows is conditioned by the fact that planet Earth, as the subject matter for the discipline of Geography, is significantly non-homogeneous in both its physical geographical and human geographical traits, and this condition forms the basis for various kinds of spatial polarity. Usually this polarity has a tendency to precipitate spatial flows. Within the scope of physical geography these flows behave according to physical laws, and are manifested in the forms of wind streams and water flows. Wilson (1969) used the term "social physics" as an analogy between physical phenomena and social interaction. Within the scope of human geography these flows are induced by various manifestations of human behaviours, and this will be of interest in the following paragraphs.

In human geography, spatial flows (spatial interactions) have the character of aggregated individual horizontal flows, mobilities and contacts of persons, goods, finances and information. These attributes have their bases in the accomplishments and satisfaction of human needs, demands, purposes, or "projects", as they are called in time-geographical terminology (see e.g. Lenntorp, 1976; Pred, 1977; Timmermans, et al., 2002). In this respect, Golledge and Stimpson (1997) distinguish between two aspects of human behaviours: spatial behaviours and behaviours in space. The former concept refers to real movements in physical space; the latter concept comprises decision-making processes that underlie the actual spatial flows. They are goal- or "project"-oriented, to once again borrow from time-geographical terminology. Even though quantitative geography preferably works with the manifestations of spatial behaviours, the underlying processes should also be borne in mind. Within quantitative geography the role of spatial behaviour and perceptions is mostly reflected in the studies of movements, particularly related to the accessibility and shopping behaviour (see e.g. Blommestein, et al., 1980; more recently Kwan, 1998; Haynes, et al., 2003; Kwan, et al., 2003; Dijst, et al., 2008 to name just a few studies).

Spatial flows can be considered as reflections of both intentional and unintentional behaviours by individuals and society as an aggregation of individuals. An individual has to consider two moments, when speaking of spatial behaviours/behaviours in space, in order to satisfy psychological, social and economic needs (inter alia): the advantage of location and gaining maximum benefit from it, and the principle of least effort (Zipf, 1949) and optimising movements. Again, the heterogeneity of geographical space plays its role and the generally underlying geographical trait, distance, more precisely the relative distance, assumes crucial significance (for this factor, see Tobler, 1970 and his "first rule of geography"; Morrill, 1974 and his theory of the spatial organisation of society based, besides other factors, on the maximisation of spatial interaction; Abler et al., 1972 on the importance of relative space; and Ullmann, 1980 on "geography as the discipline of distance").

The aggregation of individual spatial behaviours and behaviours in space produces distinct spatial patterns, as some aspects of such behaviours gain importance over others, based on the hierarchy of needs and capability, coupling and authority constraints in spatio-temporal behaviours (see Lenntorp, 1976, Pred, 1977). Examples of situations that concern most of society are the residence-workplace relationships, residence-school relationships, shopping trips and leisure trips. These types of trips are largely responsible for the formation of spatial interaction patterns. Attention should also be paid to the temporal aspects of the above-mentioned situations, not only from the point of view of their evolution over time, but particularly from the point of view of their rhythm or period. Thus movements with a daily period of repetition are important for the purposes discussed in this paper. Both spatial flows and rhythms of human behaviours form recurring and regular behavioural patterns, which result in the spatial organisation of society, into the geographical organisation of space (see the classic works of Haggett, 1965; Abler et al., 1972; Morril, 1974). The conceptualisation of these patterns is discussed in the following section.

3. Functional regions

The first indications of interest in regions as organisational structures based on functional linkages occurred in the late pre-quantitative geography era (Platt, 1928; Brush, 1953; Robinson, 1953; Ullman, 1980, based on the ideas put forward by him in the first half of the 1950s). The greater attention paid to the patterns of spatial flows is related to the rise of quantitative geography that started in the late 1950s/early 1960s. Nystuen and Dacey (1961), Haggett (1965) and later Brown and Holmes (1971), used the term nodal region. In this instance, the spatial flows are oriented towards a core, a centre or a node, and the concept was inspired by the works of Dickinson (1930), Christaller (1933), Lösch (1940) and Isard (1956). All these approaches stressed the orientation of interaction movements towards a centre, a node.

During the same decade the use of another term occurred: functional region, but its lucid and rigorous definition was not stated, and sometimes it was used interchangeably with nodal region. As examples, consider: Philbrick (1957: 302) speaks of "areal functional organisation", then operates with the concept of nodality; Dziewoński (1967) quotes both terms as individual, Berry (1968) speaks of the organisational and functional aspect of these regions, though he considers nodality and polarisation to be their basis; Abler et al. (1972) stress functional relationships within functional regions; Morrill (1970) says in the first edition of his book that nodal region is a better term for functional region, while Grigg (1967) suggested that the term functional region be preferred to the term nodal region, although he saw them as near synonyms. In contrast, Brown and Holmes (1971) differentiated between the two terms. The ambiguity between the terms nodal region and functional region was discussed later, for instance by Symanski and Newman (1973). Unequivocal definitions for functional regions were put forward by Johnston and Rossiter (1981), who, in the case of planning regions conceived as functional regions, omitted the notion of the necessary orientation of interaction movements towards a node.

Based on our own earlier work (Klapka et al., 2013a; Halás et al., 2015) and inspiration drawn from Goodman (1970), Smart (1974), Bezák (2000), Karlsson and Olsson (2006), Farmer and Fotheringham (2011), we venture to put forward a simple and general concept of a functional region for theoretical discussion. In this respect, a functional region is seen as an organisational structure based on patterns of any relevant horizontal spatial relationships (e.g. vectors, interactions, movements, flows, etc.), and the concepts of functional regional autonomy and self-containment of a region that can be expressed by two interlinked principles: the principle of external separation and the principle of internal cohesiveness. This means that spatial relationships (their number, intensity) are maximised within a functional region and minimised across its borders, which ensure a high degree of functional regional autonomy (self-containment) for each respective functional region. Such a concept of a functional region asks for a simple identification criterion of a minimum of 50% of incident spatial relationships to occur within a region (nevertheless, in practice the percentage is usually higher) – see Fig. 2.

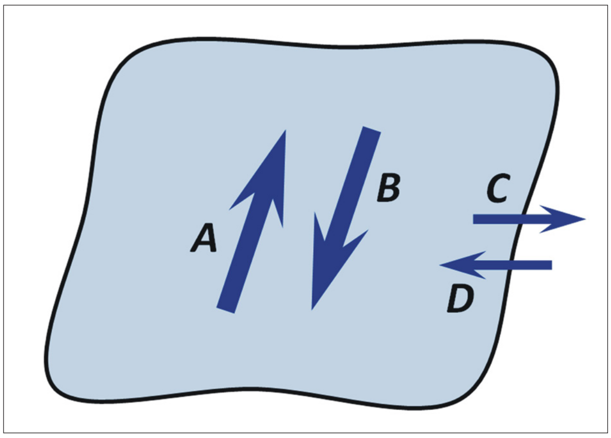

Fig. 2: Self-containment of a functional region
Source: Klapka, et al. (2013a)

Mathematically the self-containment of a region is expressed by $(A + B) > k(C + D)$; $k \geq 1$ where A and B are inner flows, C and D are cross border flows, and k is a coefficient setting the level of self-containment.

A finer classification of functional regions can be based on two criteria: inner structure and the character of region-organising relationships. As for the former criterion, functional regions reflect a so-called situational context (Ullman, 1980), when number, direction and intensity of horizontal spatial relationships vary across the space. This type of an organisational unity infers that such regions usually have a complex and non-homogeneous inner structure (unlike formal regions). In this respect, at least five theoretical models of functional regions can be distinguished (Klapka, et al., 2013a), see Fig. 3:

1. a functional region with a random pattern of inner spatial relationships;
2. a functional region with an oriented ordered pattern of inner spatial relationships, characterised by prevailing directions of flows;
3. a functional region with a channelled ordered pattern of inner spatial relationships, characterised by a concentration of flows into communication channels;
4. a functional region with a circular ordered pattern of inner spatial relationships, characterised by circulating flows; and
5. a functional region with a nodal ordered pattern of inner spatial relationships, characterised by a direction of flows towards a core (node).

Even though nodal regions are the most frequent instance of a functional region, the remaining instances in Figure 3 are not mere theoretical constructions, but they objectively exist. For instance, migration flows along short distances within a functional region at a local level, and family visits within a particular city zone have rather random patterns (see e.g. an earlier comment by Greer-Wooten and Gilmour, 1972). Some of the types can be determined by physical constraints and barriers such as a mountain range, a coastline, a huge river, etc. An important role in the spatial distribution of interactions is played by the shape and location of barriers. The less frequent type of circular flow can occur in this respect, for instance around a large lake which is a tourist attraction.

According to the second classification criterion, the character of a region-organising relationship, various types of movements (travel-to-work, travel-to-school, travel-

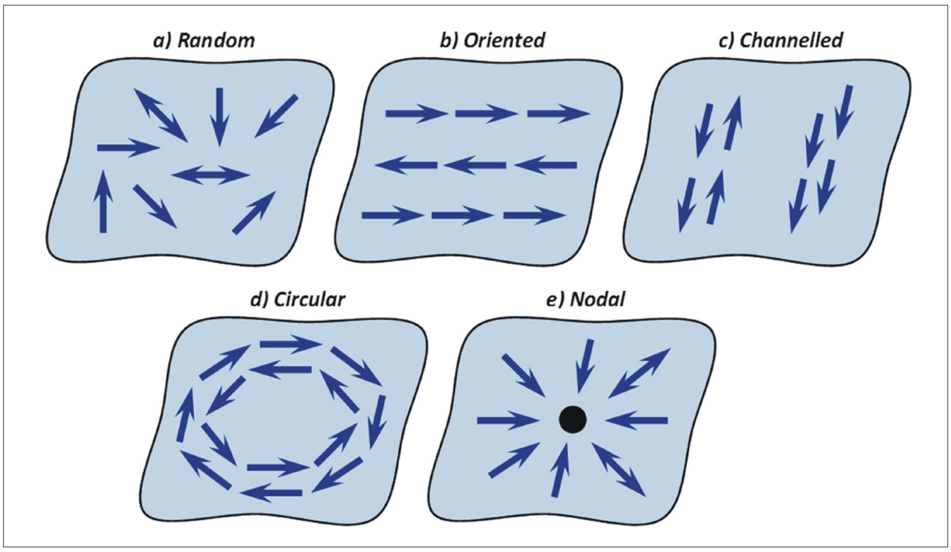

Fig. 3: Functional regions according to their inner structure
Source: adjusted according to Klapka, et al. (2013a)

to-services, leisure travels, etc.), their rhythm (e.g. daily, weekly) and types of core (e.g. urban, polycentric) are used to distinguish between functional regions. Thus functional regions based on travel-to-work flows are referred to as local labour market areas (originally discussed for example, by Goodman, 1970; Smart, 1974), or travel-to-work areas (originally discussed for example, by Ball, 1980; Coombes and Openshaw, 1982). Functional regions based on flows directly to an urban core are referred to as functional urban regions (originally discussed for example, by Berry, 1973; Hall and Hay, 1980), or, in cases where the flows have a daily rhythm as daily urban systems (originally discussed for example, by Berry, 1973; Hall, 1974; Coombes et al., 1979). All of these types of regions, as evidenced from the relevant literature, can be considered special instances of a general functional region.

Figure 4 shows a graphical expression of the most frequent types of specific functional regions, where the basic criterion, self-containment, is supplemented by further optional characteristics. Thus the functional urban region (Fig. 4a: FUR) needs to be organised around an urban core, the daily urban system (Fig. 4b: DUS) needs to be defined by daily movements and rhythms, and the local labour market area (Fig. 4c: LLMA) needs to be based on the interaction between workplace and residence.

4. Functional regional taxonomy

4.1. Conceptual framework

Functional regions are products of a functional regional taxonomy. A functional regional taxonomy is understood to be a set of approaches, methods and techniques used for the identification and definition of functional regions, which are usually based on the analysis of spatial relationships (interaction, movement, flows) between defined segments of geographic space. As such it is a part of a traditional and wide-ranging branch of human geography, i.e. spatial analysis and quantitative geography (see for example, Coombes, 2000).

A functional regional taxonomy has to take into account three crucial limitations. The first relates to the problem of the identification of geographical objects and the relevant hierarchical level needed for decisions concerning the choice of spatial zones to act as building blocks for a functional regional taxonomy. This can be called the principle of a basic spatial unit. The second limitation is expressed by the continuous character of geographic space and the distance separating basic spatial units. Again the first law of geography (see above reference to Tobler, 1970) is important in this respect. This limitation has advantageous effects in the formation of separated functional regions without the need to include information on the spatial neighbourhood of basic spatial units. The third limitation relates to the so-called modifiable areal unit problem (MAUP), which is addressed for instance by Openshaw (1984), Fotheringham and Wong (1991) and Unwin (1996).

A functional regional taxonomy is in fact an inherent part of MAUP (Baumann, et al., 1983; Cörvers, et al., 2009; Mitchell and Watts, 2010), as any effort to produce larger areas (regions) from a set of arbitrary and modifiable objects (basic spatial units) faces a considerable degree of spatial uncertainty and spatial bias. MAUP consists of two interlinked questions: how many larger areas should there be?; and, which means of amalgamating geographical objects

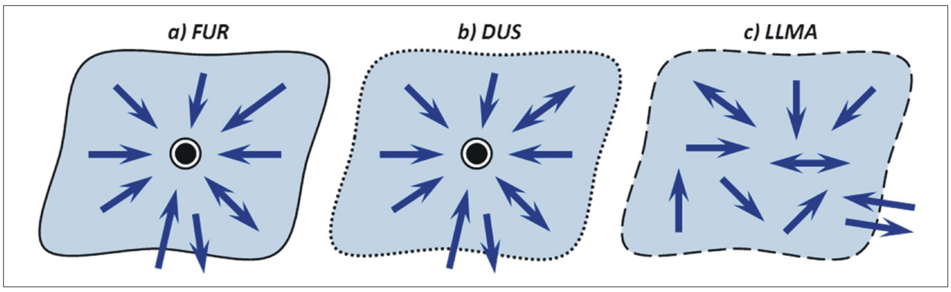

Fig. 4: Functional regions according to optional characteristics. Source: adjusted according to Klapka, et al. (2013a)

into larger areas should be used? In both cases, there are an almost infinite number of choices. The first question is known as the scale problem; the second question is known as the aggregation or zoning problem.

Two conceptual prerequisites frame the scope of a functional regional taxonomy: it is goal-oriented, and it has an exploratory rather than confirmatory character. The first prerequisite demands that there is a rigorous objective stating what is to be reached by a functional regional taxonomy and why. The second prerequisite holds that the results of a functional regional taxonomy are not known in advance. It should also be observed that there is no sole correct methodology for the analysis of interaction data, and that different approaches, methods and techniques can provide considerably different results (Van der Laan and Schalke, 2001; Klapka, et al., 2014).

Generally, the identification and definition of functional regions can be achieved through one or both of two interlinked tasks that can be viewed as two perspectives on the same problem. The first task is to search for similarities in spatial relationships across geographical space. The similarity is expressed by the intensity of spatial relationships, when higher intensity implies higher similarity, i.e. significant linkages between geographical objects. The second approach (see e.g. Coombes, 2000) is a quest for boundaries across geographical space. Retaining the argumentation of this paper based on the concepts of spatial non-homogeneity and spatial interaction, the boundaries can be conceived as areas where few or no spatial relationships occur.

Finally, there is the issue of the contiguity of functional regions, i.e. the difference between typological and individual functional regional taxonomy. The procedures leading to the definition of individual functional regions should theoretically comprise a contiguity constraint. Some methods, such as the Intramax (see below), comprise such a constraint. In contrast, the majority of approaches do not include this constraint, since it is the character of a space, the role of distance and behavioural constraints that produce contiguous typological functional regions, and these can be considered to be individual functional regions. To sum up, the taxonomic similarity of basic spatial units is closely related to the spatial proximity of these units.

4.2 Typology of approaches

Existing typologies of approaches leading to the definition of functional regions have been presented by Coombes (2000), Van der Laan and Schalke (2001), Casado-Díaz and Coombes (2011), Farmer and Fotheringham (2011), and Klapka et al. (2014), among others. Some of the terms in Table 1 have been used by the above-mentioned works, but sometimes with different meanings (see for example, the definition of hierarchical methods by Casado-Díaz and Coombes, 2011). In this paper, an attempt to provide a more detailed classification of functional regional taxonomic tasks is put forward in order to add to this field of study. All approaches come from the analysis of an interaction matrix, storing the information on contacts (i.e. flows and linkages) between basic spatial units.

Four criteria, each allowing two possibilities, are used in order to classify methodological approaches to the identification of functional regions (i.e. regional classes). The criteria are ranked in descending order from more generic to more specific (see Tab. 1).

The first criterion is based on the direction of a regional class formation, when either basic spatial units are grouped into larger clusters, or the set of basic spatial units is divided into smaller subsets. The second criterion distinguishes between methods that follow a general clustering principle, where a regional class is formed in one stage, and methods that are comprised of several stages, all of which can have various objectives. The basic difference is that, in the former case, once two basic spatial units (or clusters) are amalgamated, they can never be dissolved, while in the latter case the final clusters are formed after all stages are completed and all the rules fulfilled, and it is possible that a proto-cluster can be dissolved during the procedure. The third criterion distinguishes between tasks when the number of final clusters is known in advance (non-hierarchical methods) or it is not (hierarchical methods)[1]. Finally, the fourth criterion distinguishes between cases where the interaction matrix is interpreted as a graph, and where it is conceived as a numerical expression of the dissimilarity of respective basic spatial units.

Theoretically, each approach should be classifiable within each criterion. It must be admitted that some approaches do not exist, for logical reasons, or they are not used for practical reasons (they do not provide geographically acceptable results or are too demanding for computer processing). A survey of the literature shows that several selected approaches have been favoured so far. Graph-oriented methods occurred first (e.g. Nystuen and Dacey, 1961; Slater, 1976; Holmes and Haggett, 1977) as their application is quite simple, without the need for robust computation. In principle, they use solid or floating thresholds in order to identify significant flows,

Criterion	Approach
1. Direction of a regional class formation	*Agglomerative*
	Divisive
2. Character of a class-forming procedure	*Clustering*
	Rule-based (multistage)
3. Form of a regional class formation	*Hierarchical*
	Non-hierarchical
4. Form of an interaction matrix analysis	*Graph-oriented*
	Numerical

Tab. 1: Classification of approaches to a functional regional taxonomy. Source: authors' design

[1] This criterion should not be confused with a result of functional regional taxonomy, which can be hierarchical (more layers of usually nested functional regions) and non-hierarchical (only one layer of functional regions). In this case the terms hierarchical and non-hierarchical refer not to the result, but to the form of construction of a regional layer.

which occur on an oriented graph. The significant flows can be based for instance on primary linkage, minimum directionality linkage, salient linkage, or hierarchical linkage (Holmes and Haggett, 1977). These methods often produce unsatisfactory results, yielding disordered regional patterns which need subjective intervention in order to acquire contiguous and separated regional classes. Their strength lies in the simple preliminary analysis of a regional system. These methods have been used relatively recently, however, for example by Van der Laan and Schalke (2001), Karlsson and Olsson (2006), Drobne et al. (2010), Halás et al. (2010), and Farmer and Fotheringham (2011).

The second group of methods that has been widely used is based on numerical and clustering approaches. These methods involve the application of general cluster analysis on spatial problems using various linkage measures. Brown and Holmes (1971) used the functional distance approach based on mean first passage time (MFPT), where the interaction between two basic spatial units is taken as the measure of similarity in taxonomic space. Keane (1978) and, relatively recently, Cörvers et al. (2009), have also applied the functional distance method. According to the number of citations, the most successful approach in this group is the Intramax procedure. It was designed by Masser and Brown (1975) and refined by Masser and Scheurwater (1978), in reaction to comments made by Hirst (1977). This method builds upon Ward's (1963) hierarchical clustering procedure, which is adjusted for interaction data. The Intramax approach was applied by Nel et al. (2008), Drobne and Bogataj (2012), and Landré (2012) relatively recently.

The third group of methods, the so-called rule-based procedures, is comprised of the approaches most widely used today. The origins of the rule-based approaches can be found in the work of Smart (1974). His basic idea was further developed in great detail into a complex regionalisation algorithm designed by the Centre for Urban and Regional Development Studies (CURDS) in Newcastle, UK. Up to the present, three variants of the CURDS algorithm have been developed (Coombes et al. 1982, 1986; Coombes and Bond, 2008; Coombes, 2010). The principle of these methods comes from the definition of a set of rules that are applied in several stages and determine the results of the analyses. The rules are often used iteratively in order to reach or approximate an optimal solution. Minor adjustments to the algorithms regarding the constraint function were proposed by Casado-Díaz (2000) and Halás et al. (2015). Apart from the above-mentioned works concerning the territory of Great Britain, multistage methods were applied in a number of mainly European countries: Italy (Sforzi, 1997), Slovakia (Bezák, 2000; Halás et al., 2014), Spain (Casado-Díaz, 2000), New Zealand (Papps and Newell, 2002; Newell and Perry, 2005), Australia (Watts, 2004), Belgium (Persyn and Torfs, 2011), Poland (Gruchociak, 2012), and the Czech Republic (Klapka et al., 2014). There are also other types of rule-based approaches: for example, a graph theoretical multistage approach, differing from the CURDS algorithm, has been proposed by Kropp and Schwengler (2016).

Even this smaller number of three groups of methods of functional regional taxonomy that were put into practice gave rise to discussions concerning two points: a comparison of the methods, and criticism of the methods. The insufficiencies of the graph theoretical methods have been mentioned already. The numerical and clustering approaches were criticised for being too heuristic (Ball, 1980; Coombes and Openshaw 1982). In contrast, the multistage methods faced criticism for being subjective in a certain way and using pre-defined arbitrary criteria (e.g. Mitchell and Watts, 2010). Halás et al. (2015) proposed a procedure to mitigate the effects of arbitrary choice in the CURDS algorithms.

Despite the criticisms, however, the results of different methods were often compared. Masser and Scheurwater (1980) compared the functional distance method, the graph theoretical method iterative proportional fitting procedure (IPFP), and the Intramax method. Fischer et al. (1993) compared the IPFP and Intramax procedures. Watts (2009, 2013) made comparisons between the results of the CURDS algorithm and the Intramax method. Drobne et al. (2010) compared some more sophisticated graph theoretical methods with the Intramax approach. Klapka et al. (2013b) compared the results of the CURDS algorithm with simpler graph theoretical methods based on the primary linkage. Landré and Håkansson (2013) compared the results of the Intramax with graph theoretical methods. Most works cited in this paragraph reach the conclusion that aggregation procedures such as Intramax and the CURDS algorithm produce more correct results than graph theoretical methods and matrix transformation methods (e.g. IPFP). The question of whether to use hierarchical aggregation (Intramax) or rule-based aggregation (the CURDS algorithm) seems to remain open: it depends in part on the objectives of the research, but also, paradoxically, on subjective factors due to the preferences of the researcher.

5. Importance of functional regions and discovering future prospects

The problem of the definition of functional regions has a wide range of implications for the development of both geographical theory and practice. As far as the practical point of view is concerned, it has long been acknowledged by Haggett (1965) and Dziewoński (1967) that functional regions can serve better as a geographical tool for normative use than administrative regions. Functional regions have a vital role in fields such as spatial planning, regional economics, statistical geography, transport geography, etc.; effectively, in all cases where there is a need for some kind of spatial units with internal geographical logic in order to reduce possible spatial bias. It is considered that administrative, political and some statistical divisions do not necessarily reflect existing geographical realities, and that they may manifest a significant degree of inefficiency (see for instance, Coombes, 2010; Casado-Díaz and Coombes, 2011; Farmer and Fotheringham, 2011).

The theoretical implications appear to be more inspiring for geographers to acknowledge the importance of the study of functional regions. Such implications are more complex and mutually conditioned and unfolded. Most of them are grounded in spatial uncertainty or in spatial bias, which is a specific manifestation of the role and property of most geographic (spatial) characteristics. In this argument, spatial uncertainty is occasioned by the continuous character of geographic space and its measurable elements. In the most general sense, the above-mentioned MAUP emerges again. Every effort to define a system of functional regions faces questions concerning the number and composition of regional classes. These questions are complicated to solve and that is the challenge for future research. The solutions to MAUP, however, are strongly dependent on the research objectives used in defining functional regions. Possible directions of research can be aimed at the analysis of spatial associations, spatial distributions and spatial variability, or any combination of such phenomena.

In a more specific sense, spatial uncertainty unfolds from a more probabilistic rather than a deterministic concept of functional regions, which is again a reflection of the continuous character of geographic space. This approach concedes that the level of belonging of geographic objects (in this case, basic spatial units) to a regional class need not be an unambiguous inference. This idea comes from fuzzy set theory, where the membership of an object in a set can vary from zero to absolute validity. Coombes (2000) was among the first to suggest a more fuzzy approach to the definition of functional regions. Feng (2009) presented a method for the assessment of fuzziness in regional systems through the adoption of a so-called membership function. This function was later improved by Watts (2009, 2013). The adoption of the fuzzy set approach to functional regions opens up the possibility of identifying overlapping functional regions, even though their existence is usually ruled out by the principle that a basic spatial unit should belong to just one regional class. The issue of overlapping functional regions is discussed by Killer and Axhausen (2011), and the issue of the fuzziness of regional systems is discussed further by Feria et al. (2015). The fuzzy set approach, taken more generally, can be a cornerstone for the identification of so-called pulsating functional regions, which can vary in space and time and, turning full circle, are again more general consequences of spatial uncertainty.

Another future prospect in the study of the definition of functional regions is linked to the preceding paragraph and it is grounded in the search for an efficient way to reduce the risk of spatial uncertainty in the results of functional regional taxonomy. It is a characteristic of most procedures defining functional regions that after they reach a solution, according to set parameters, they terminate. These procedures are based on the so-called greedy algorithms. There might be a better solution with regard to the total self-containment or fuzziness of a regional system, however, which has not been identified by any particular method. This clearly requires a refinement of the distribution of basic spatial units into regional classes.

An emerging field of study in this respect is the application of evolutionary or genetic algorithms (clustering techniques) drawing inspiration from biology and genetics. Pioneering works in functional regional taxonomy were put forward by Flórez-Revuelta et al. (2008), Martínez-Bernabeu et al. (2012), and their approach was modified by Alonso et al. (2015). These heuristic methods generate a number of variant solutions (generations) to the large regionalisation problem. They are based on evolutionary principles, such as selection, mutation and crossover, and optimise a so-called fitness function.

Another way to tackle the issue of refining existing solutions to functional regionalisation is the use of non-hierarchical clustering strategies. Regarding this, new prospects are offered by the application of soft clustering methods, such as the fuzzy c means (FCM) algorithm, which is a soft variant of the frequently used non-hierarchical k means algorithm (for general definition and use, see for example, Bezdek et al., 1984, and Yang, 1993). As in the preceding case of algorithms based on evolutionary computation methods, a crucial role in these methods is played by a so-called objective function, which means that it should be very well defined and designed. The principle of the methods is grounded in the search for a global optimum through maximisation (or minimisation – it depends on the logic of the clustering algorithm) of the objective function. In a functional regional taxonomy this means that basic spatial units are iteratively reallocated between regional classes until there is no improvement in the value of the objective function, and all predefined criteria, such as self-containment and size, are met.

6. Special Issue on functional regional taxonomy

The present theoretical paper has introduced this Special Issue of the Moravian Geographical Reports on functional regions and functional regionalisation. It covers a wider spectrum of related problems in five papers, presenting specific contributions to the field of methodology and use of functional regions. Drobne and Lakner discuss the use of different objective functions in hierarchical aggregation procedures for the definition of functional regions. Martínez-Bernabeu and Casado-Díaz propose a methodology, based on evolutionary computation, to overcome the insufficiencies caused by limitations exposed by basic spatial units in the construction of functional regions. Erlebach, Tomáš and Tonev present the results of three methods to define functional meso-regions of the Czech Republic. Klapka, Halás, Netrdová and Nosek discuss the suitability of functional micro-regions for spatial analysis and present a comparison of functional regions and administrative regions in this respect. Olsson presents a spatial interaction modelling approach, particularly the issue of accessibility measures based on the use of distance-friction parameters, to the identification of functional regions.

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