Spatial-temporal Modeling of Linguistic Regions and Processes with Combined Indeterminate and Crisp Boundaries

Johannes Scholz, Thomas J. Lampoltshammer, Norbert Bartelme and Eveline Wandl-Vogt

Abstract The paper elaborates on the spatial-temporal modeling of linguistic and dialect phenomena. Language Geography—a branch of Human Geography—tries to enhance the visual exploration of linguistic data, and utilizes a number of methodologies from GIScience, whereas publications focusing on analyzing linguistic data in GIScience are hard to find. This research work highlights the representation of language and/or dialect regions with combined indeterminate and crisp boundaries—i.e. frontiers and borders. Both boundary "types" are necessary in order to model the spatial-temporal dynamics of language phenomena. The article analyzes the emerging, ending, moving and merging of linguistic/dialect regions and phenomena with respect to space and time and the boundary types. In order to represent frontiers or indeterminate boundaries, fuzzy logic is employed.

Keywords Linguistic geography · Fuzzy logic · Geographic information science

1 Introduction

The intention of Language Geography—a branch of classical Human Geography (Delgado de Carvalho 1962)—is to enhance the usability of digital language and dialect databases and to foster the visual exploration of linguistic data. Currently,

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linguistic phenomena are mapped in a static manner, which results in maps with dialect regions or isoglosses. Isoglosses define the geographic boundary of a linguistic feature, such as the pronunciation of a vowel, the meaning of a word, or use of some syntactic feature.

Due to the fact that language and dialect are dynamic phenomena per se, a digital representation should be able to model this fact. Hence, we apply the theory of fuzzy sets (Zadeh 1965) and indeterminate boundaries to Language Geography. Given the fact that language regions and isoglosses may move over time, boundaries between adjacent regions are not always crisp—but they can be crisp if, e.g., a natural barrier hinders the movement of people and thus the exchange of language. This is true for, e.g., mountain chains or oceans, which constrain the movement of people. The same can be said about barriers having been introduced in the late 19th and in the 20th century, when language became a major identifier for each country and there were more and more efforts to use political boundaries also for outlining cultural (and especially linguistic) domains. Nerbonne (2010) emphasizes that the change in dialectal spatial variation is gradual, thus supporting the argumentation of fuzzy linguistic boundaries.

In addition, language islands and regions may arise from scratch as well as existing language regions or islands may disappear over time—which has to be modeled accordingly. Globalization and urbanization fosters the creation of new language islands and regions within existing language regions. Hence, the regions have no crisp border, but share a certain part of space with fuzzy memberships of the involved linguistic regions (Burrough 1996; Worboys 1998).

The article covers the spatial-temporal modeling of language phenomena based on fuzzy sets, indeterminate boundaries and spatial-temporal change of spatial entities (Medak 1999; Hornsby and Egenhofer 1997, 2000). Hence, linguistic processes are analyzed regarding the implications on their according spatial-temporal entities and processes.

In this paper, we assume that boundaries between language phenomena may be fuzzy—with different degrees of fuzziness. Fuzzy boundaries represent the gradual transition zones between language phenomena. Nevertheless, the boundary may show an infinitely small transition zone, which classifies the boundary as crisp. We underpin this argumentation of fuzzy and crisp boundaries with an analysis of landforms and language boundaries.

In this article we do not cover the influence of media on language and dialect, due to the fact that this might have a more widespread impact on language itself, rather on merely its geographic extent.

2 Relevant Literature

In the following paragraphs, we highlight relevant literature for this article. We elaborate on publications from Geographic Information Science, Linguistics, Geolinguistics, and Dialectology.

2.1 Geographic Information Science

Literature from Geographic Information Science (GIScience) that contributes to Linguistics or Dialectology is very rarely found. There exist a handful of papers that are of relevance (e.g., Hoch and Hayes 2010; Silber et al. 2012; Scholz et al. 2008), which are discussed in Sect. 2.2. Relevant in this context is the theory of fuzzy sets from Zadeh (1965). Regarding Geographic Information Science, the publications by Burrough (1996) and Worboys (1998) cover the handling of objects with fuzzy boundaries and imprecise spatial data respectively. To model spatial-temporal dynamics in language and dialect regions, we refer to the work by Medak (1999), Hornsby and Egenhofer (1997), as well as Hornsby and Egenhofer (2000).

More recent publications deal with events and geographic phenomena, developing an algebraic theory to represent spatial-temporal events (Worboys and Hornsby 2004; Worboys 2005). Grenon and Smith (2004) developed a modular ontology for dynamic features that attempts to represent the real world. They rely on two concepts, which seem incompatible at first a glance: spatial-temporal snapshots of the universe of discourse and spatial-temporal processes in general. Both ontologies are designed in a way that they can interact with each other. Hornsby and Cole (2007) highlight an event-based approach to model moving objects. Based on the pattern of events of an object they try to create of semantics of events. Nixon and Hornsby (2010) extended the existing theory by adding geolifespans to objects—meaning that objects can be created, can vanish, can convert, merge, etc. In addition, the longevity of objects is modeled as geolifespan classes, where also transitions between the classes are possible.

2.2 Linguistics, Geolinguistics, and Dialectology

Classical language and dialectology atlases present their data with the help of point symbols or a thematic map (e.g., dbo@ema; REDE). Additionally, language boundaries are marked with isoglosses, a concept that has been critically discussed by Pi (2006), highlighting the concept of isographs.

An overview of contemporary mapping and visualization techniques in linguistics and dialectology is presented in the book edited by Lameli et al. (2010). Some researchers in linguistics advocate for using "honeycomb maps"—i.e., Delaunay triangulations or Voronoi diagrams—which are constructed around point observations (Goebl 2010; Nerbonne 2009, 2010). Rumpf et al. (2009) proposed a visualization of linguistic features using kernel density estimation. Subsequently, Rumpf et al. (2010) published a paper that elaborates on geographical similarities on area-class maps. In this paper, cluster analysis is employed in order to extract groups of similar structured maps.

It is a notable fact that in linguistics or dialectology, researchers use methods originating from GIScience to a certain degree, while publications on the analysis

and mapping of linguistic data in GIScience are hard to find. Exceptions are the work of Lee and Kretzschmar (1993), Hoch and Hayes (2010) and Silber et al. (2012). Partly Bartelme and Scholz (2010) and Scholz et al. (2008) attempted to discuss the GIScience perspective of the project "Database of Bavarian Dialects electronically mapped" (Wandl-Vogt et al. 2008). Jeszenszky and Weibel (2015) propose four research questions to analyze the nature and behavior of linguistic boundaries. Generally, Nerbonne (2010) states that the theory of dialect continua indicates that the change in dialectal spatial variation is gradual.

3 Boundaries: Crisp Versus Indeterminate Boundaries?

Boundaries are present in everyday life. Thus, they are present in many ways in our mind and in reality and have different nature, properties, and dynamics. This section covers a definition of boundaries and highlights the spatial-temporal nature of borderland processes. In addition, it clarifies the terms border, borderland, and frontier, as well as it provides an introduction to fuzzy theory in relation to the afore-mentioned concepts. Additionally, we analyze linguistic boundaries and underlying landforms in order to evaluate if both, crisp and indeterminate boundaries, between language phenomena do exist.

3.1 Theory of Boundaries

Parker (2006) and Kristof (1959) list a definition of a boundary based on the Oxford English Dictionary, which defines boundary as something "that which serves to indicate the bounds or limits of anything" (Rankin and Schofield 2004, p. 2). This rather unspecific definition indicates that boundaries are unspecific divides that represent limits of any kind. Due to this generality, the term should be defined in a more precise way. For example, Kristof (1959) explains that the two words 'frontier' and 'boundary', although in everyday speech interchangeable, at a closer look show substantially different meanings. While a boundary is a line, a frontier is typically an area, part of a whole, specifically that part that is ahead of the hinterland. In German, the word 'Mark' comes close, in Slavic languages, the words 'Krajina' or 'Ukraina', which also have attained a geopolitical meaning. Parker (2006) even goes one step further, defining the terms 'boundary', 'border', 'frontier', and 'borderland'. He defines 'borders' as "linear dividing lines, fixed in a particular space, meant to mark the division between political and/or administrative units" (Parker 2006, p. 79). The term 'frontier' is defined as a region with interpenetration between two previously distinct objects (see also Kristof 1959). According to Parker (2006), such a zone could separate various types of political or cultural units and such regions could also be made up of empty areas without physical contact. A 'frontier' is seen in literature as a zone where a number of

boundaries overlap and intersect—hence frontiers are made up of boundaries including, geographic, political, demographic, political, or cultural ones. The term 'borderland'—as defined by Parker (2006)—represents the "region around or between political or cultural entities where geographic, political, demographic cultural and economic […] processes may interact to create borders or frontiers" (Parker 2006, p. 80). Following this definition, we can conclude that there are two types of boundaries that can be found in borderlands: borders and frontiers.

Boundaries and borderlands can be looked at in two opposite ways, either by paying attention to their separating role or by seeing them as a place where ideas—and also languages—meet and partly overlap or rather blend into each other. By emphasizing the chance to meet instead of only sticking to the separating aspects of boundaries, a deeper investigation of processes going on in such borderlands is highly interesting and rewarding. By the way, such a duality is quite common in GIScience, as for example in DIME (Dual Independent Map Encoding), which—for regions with crisp boundaries—defines two dual graphs that intertwine. DIME originated in 1967 at US Bureau of Census (http://www.ncgia.buffalo.edu/gishist/DIME.html). Here, this concept is being generalized to indeterminate boundaries.

According to Kristof (1959) and Parker (2006), there are several distinguishable types of boundaries. Generally, Parker (2006) lists five types of boundaries: Geographic Boundaries, Political Boundaries, Demographic Boundaries, Cultural Boundaries, and Economic Boundaries. Linguistic Boundaries—interesting in this respect—are a sub-type of Cultural Boundaries. The overview of boundary types is to be found in Fig. 1.

The nature of boundaries—either being border or frontier—is described in the following paragraph. Borders and frontiers are the opposite extremal points of the

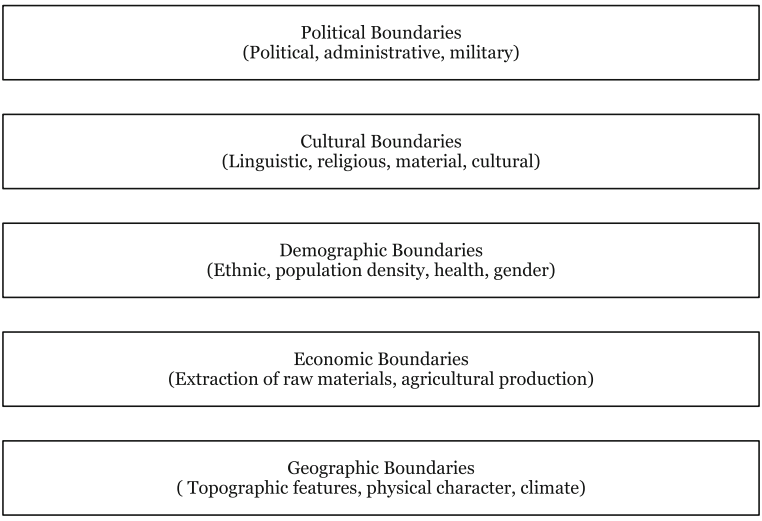

Fig. 1 Boundary types defined by Parker (2006)

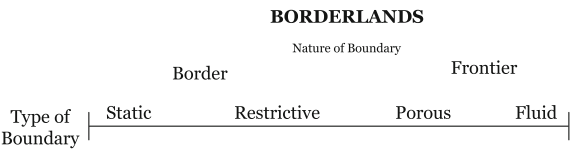

Fig. 2 Borderland continuum as defined by Parker (2006)

continuum of boundaries, where borders are hard, linear, and static, while frontiers are soft, fluid, and zonal. Figure 2 shows the interrelationships between borderlands, borders and frontiers, and boundaries. It is necessary to state that boundaries cannot be strictly classified as borders or frontiers. Hence, each boundary can be defined on the continuum between border and frontier.

There are several examples in Europe where all types of boundaries can be observed. The Karst region around the city of Trieste, as well as the adjacent Istrian peninsula offer a good base for testing all of the above statements.

3.2 Fuzzy Sets and Boundaries

As already discussed before, boundaries cannot be defined in a crisp way.

It would therefore be more appropriate to make use of the concept of zones. In consequence, the concept of boundaries is a fuzzy concept. While boundaries serve as clear separators between areas adjacent to each other, this model is an abstract one and the reality is a continuous space and not a discrete one. In addition, when descriptions such as 'large' or 'tiny' are used to describe the geographic extent of a region, a crisp and absolute quantification becomes impossible. Furthermore, specific descriptors of regions do not end at their boundaries. Intermediate 'in-between regions' reflect the decrease of an attribute of region A and the increase of another attribute of region B (Leung 1987). Ergo, alternatives to fixed quantitative descriptions are required. Fuzzy logic presents such a suitable alternative. While there is an on-going discussion whether fuzzy theory is applicable and acceptable in general (Zadeh 2008), it is fuzzy logic that enables computational approaches in areas of imprecise and incomplete information (Zimmermann 1978).

Let us elaborate on the concept of fuzzy logic by the use of a linguistic variable as show in Fig. 3. This variable in the context of granulation can be seen as a way to compress information of variables and system relations regarding input and output. In this case, the variable X can take values from U. If u is a value of X and u is precisely known, we refer to it as singular value, while in the opposite case, we refer to it as granular values of X (see Fig. 4).

For instance, let u be contained in an interval with the boundaries $[a, b]$, then $[a, b]$ is a value of X. In consequence, it can be stated that granular variables take granular values. In our case, the employed linguistic variable is a granular variable, which has linguistic labels assigned (Zadeh 2008).

Keeping these facts in mind helps to extend the concept boundaries beyond classical thinking regarding spatial planning, political strategies, and common

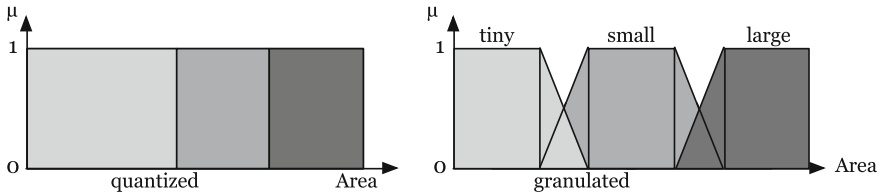

Fig. 3 Quantized versus granulated with fuzzy labels, adapted from Zadeh (2008)

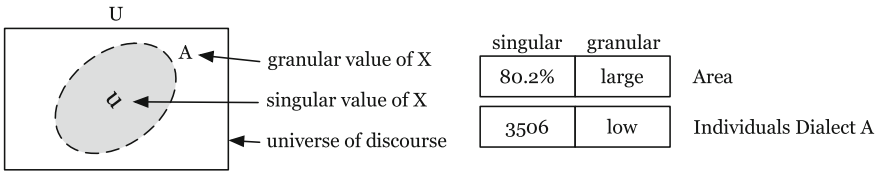

Fig. 4 Singular versus granular values, adapted from Zadeh (2008)

visualization, as well as their perception and interpretation (Allmendinger and Haughton 2009), which is necessary when working with linguistic boundaries.

3.3 Fuzzy Boundaries as Linguistic Boundaries

The definition of boundaries is necessary for linguistic processes. In addition to Nerbonne (2010), we investigate topographic landforms as physical objects that hinder or foster the exchange of language. Hence, boundaries that coincide with specific landforms may be regarded as crisp, whereas others indicate that a fuzzy boundary with a gradual transition zone exists. Furthermore, the authors explain why and how the term frontier coincides with linguistic boundaries.

An analysis of the boundaries of linguistic/dialect regions, mapped by the dboe@ema Project (Wandl-Vogt et al. 2008; Scholz et al. 2008) indicates that the boundaries of linguistic phenomena—discretized in linguistic/dialect regions—have both frontiers and borders (Bartelme and Scholz 2010). Therefore, Bartelme and Scholz (2010) analyzed the boundaries of dialect regions in the province of Styria (Austria) regarding their landform (see Figs. 5 and 6). The landform classes were determined based on the methodology published by Weiss (2001) and on SRTM90 data. The definition of landform classes is not subject to this paper; thus we refer to Weiss (2001) for details.

The results reveal (see Figs. 6 and 7) that boundaries of dialect regions are crossing plains and valleys as well as ridges. In detail, 19 % of the boundaries are crossing plains and 5 % valleys. 18 % of the dialect region boundaries cross midslope and high ridges and 49 % are overlapping with open and upper slopes.

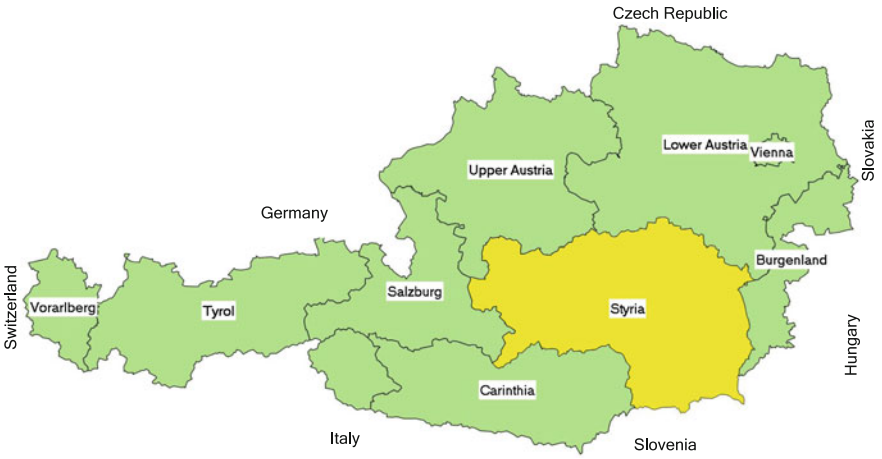

Fig. 5 The province of Styria highlighted in *yellow color*, and the neighboring provinces and countries

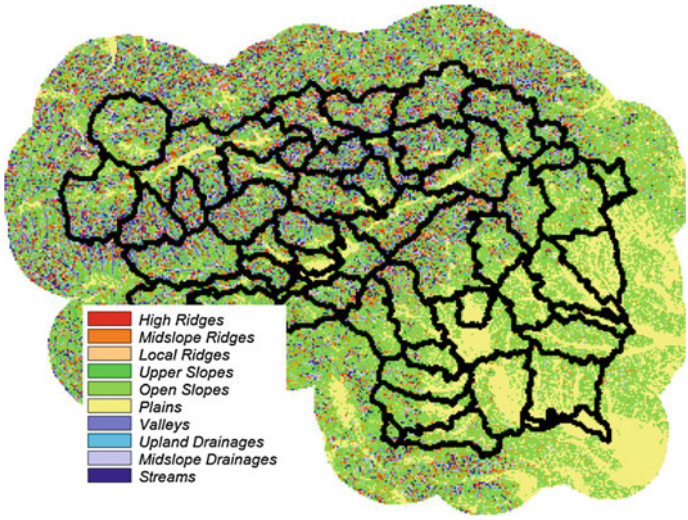

Fig. 6 Landform classes in the province of Styria with boundaries of dialect regions marked with *black lines*

If we assume that valleys and plains do not hinder the exchange of people and language in detail, we can conclude that such boundaries are *frontiers* in nature. The argument of fuzzy frontiers is also underpinned by the fact that linguistic/dialect boundaries are moving and not crisp—especially in plains and valleys. An example of such a fuzzy boundary is the boundary between the south Bavarian and the middle Bavarian dialect region. The boundary comprises a set of isoglosses

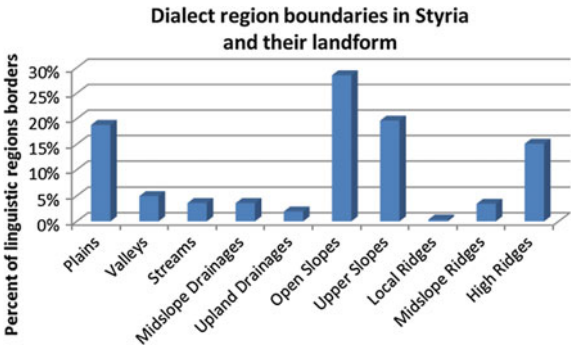

Fig. 7 Landform classes of the boundaries of dialect regions in the province of Styria

representing the boundaries of different language phenomena. Thus, the boundary is —depending on which isoglosses are chosen—not exactly defined.

On the contrary, the authors assume that high and midslope ridges are topographic phenomena, impeding the exchange of language. Thus, the boundaries are more static in nature, which leads to the conclusion that such boundaries are borders. An example for a static border is the boundary between the Alemannic and Bavarian dialect/language group. The Alemannic languages are dominant in the western part of Austria and Switzerland, whereas the Bavarian dialects are dominant in the eastern part of Austria. The boundary of the language regions is the Arlberg mountain ridge—a static border that remains fixed since 1900.

4 Linguistic Phenomena and Their Spatial-temporal Representation

The following section describes the linguistic phenomena and their spatial-temporal representation. Therefore, we utilize the theory of boundaries and fuzzy sets highlighted in the previous sections. In this section, we focus on the lifespan of a linguistic phenomenon (i.e., beginning and end), as well as moving and the merging of linguistic phenomena. The following sections are related to the publications of Medak (1999) and Hornsby and Egenhofer (1997, 2000). These publications list a number of operations that maintain or change object identity such as: create, destruct, reincarnate, issue, continue existence, continue, non-existence, spawn, metamorphose, merge, generate, mix, aggregate, compound, unite, amalgamate, combine, separate, splinter, divide, secede, dissolve, and select. A selection of these operations are depicted in Figs. 8 and 9 respectively.

The object identity operations highlighted here represent snapshots of processes. For the case of linguistic processes, which usually tend to span over several years or decades, snapshots are too coarse in terms of spatial-temporal granularity. Hence, the authors propose the modeling of linguistic processes with indeterminate boundaries—in order to represent the gradual change of linguistic phenomena.

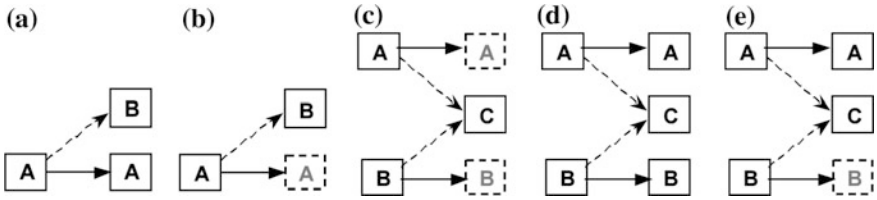

Fig. 8 Object identity operations on simple objects (Hornsby and Egenhofer 1997). **a** Spawn. **b** Metamorphose. **c** Merge. **d** Generate. **e** Mix

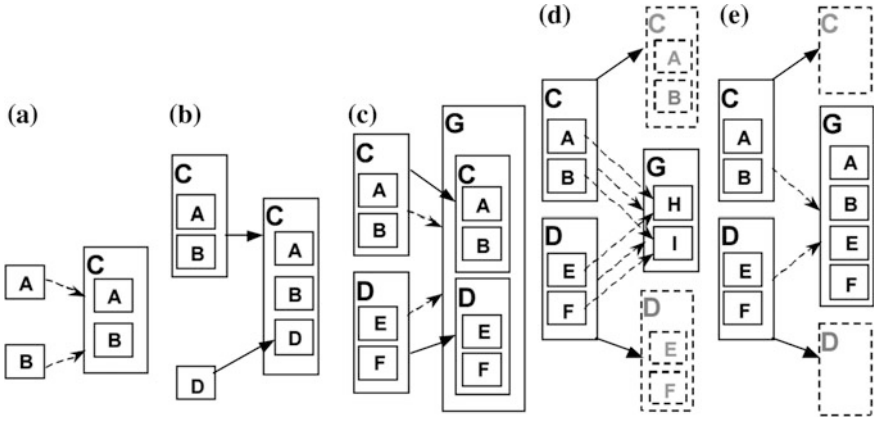

Fig. 9 Object identity operations on composite objects (Hornsby and Egenhofer 1997). **a** Aggregate. **b** Compound. **c** Unite. **d** Amalgamate. **e** Combine

4.1 Emergence and End of Linguistic Phenomena

Any linguistic or dialect phenomenon has a beginning and an end defined, with respect to the spatial-temporal dimension. The creation of a linguistic phenomenon has an origin, which can be regarded as point or geographical area. In order to model the beginning of a linguistic phenomenon, the authors propose to utilize static borders and fuzzy frontiers.

As linguistic phenomena are 'slow' processes in terms of the spatial-temporal dimension, the occurrence of a new linguistic phenomenon within a given linguistic region is a gradual process. Hence, the boundaries around a new linguistic phenomenon should not be represented by static borders but rather with fuzzy frontiers—if there is no natural barrier that hinders the exchange between people (see Fig. 10).

The situation is different, if natural barriers exist that hinder the exchange of people—and language as a result. Consider an alpine valley that is surrounded by high mountains, where exchange is only possible along the valley plain—that,

e.g., connects with other (bigger) valleys. Then, the new linguistic phenomenon needs both frontiers and static borders (see Fig. 11).

New linguistic features may occur in cities where the (im-) migration of people may influence the language and dialect(s) spoken—due to introduced subcultures. Similar to topographic hinderings, the spreading of new 'dialects' in cities may face borders, which may be induced by, e.g., different social structure of neighboring areas, topographic features such as roads, rivers, or railway lines. Different social structures of neighboring areas impede the spreading of dialects due to the fact that people do not exchange too heavily.

The ending of a linguistic feature is similar to the new occurrence of a linguistic feature—but the process works in the opposite way. The linguistic phenomenon under review is gradually "soaked up" by other linguistic phenomena—i.e., a

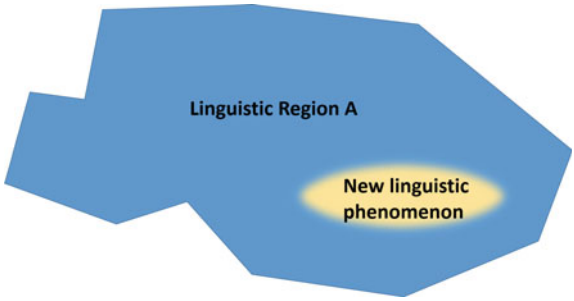

Fig. 10 Occurrence of a new linguistic phenomenon (marked in *yellow*) in an existing linguistic region—represented by the *blue rectangle*. The boundaries of the new linguistic phenomenon are fuzzy as the boundaries of a new linguistic phenomenon cannot defined in a crisp manner

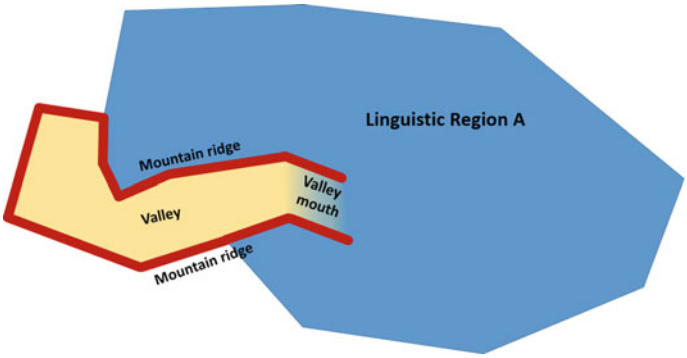

Fig. 11 Occurrence of a new linguistic phenomenon (marked in *yellow*) in an existing linguistic region—represented by the *blue rectangle*. The new linguistic phenomenon is occurring in a valley surrounded by a mountain ridge—marked with red lines—hence there are static borders. In the valley mouth exchange between the language groups can take place. Thus, the new linguistic phenomenon shows a fuzzy boundary—i.e., a frontier—there

dialect or phenomenon is not actively used by people living in that area. Hence, the boundaries are fuzzy and the space covered by the linguistic phenomenon under review gets gradually smaller, until the phenomenon disappears completely.

4.2 Moving Linguistic Phenomena

The movement of linguistic phenomena in space and time is a process that is dependent on the fact that people move and/or change their language and speaking "habits". Hence, it is obvious that those linguistic phenomena are not static in space and time. As stated above, a prerequisite for the movement of linguistic phenomena is the exchange of people and language. Due to the fact that natural barriers hinder the movement and exchange of people, whereas flat lands and valleys foster exchange, there is a need to model linguistic boundaries as static borders and frontiers (Fig. 12).

4.3 Merging of Linguistic Phenomena

If linguistic phenomena merge, we summarize under the term "merge" the following processes: mix, generate, and merge as described by Hornsby and Egenhofer (1997). Mix denotes a process where two regions unite and form a new type of region. Generate describes a process where two objects form an 'intermediate' (e.g., where they share a common border) object, whereas the original objects remain stable. Mix in the sense of Hornsby and Egenhofer (1997) denotes a situation where two objects form a new object type and one of the original objects is ending.

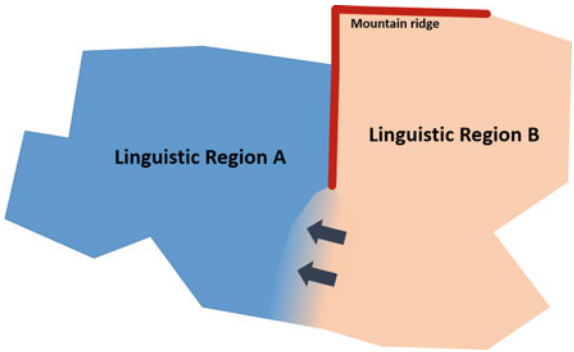

Fig. 12 Example of moving linguistic phenomena. The phenomenon B is moving into the region of the linguistic phenomenon A (marked with *black arrows*), where a fuzzy frontier exists. The mountain ridge—represented as *red line*—is hindering the exchange between the two groups, thus the boundary is of a static nature

Similar to the prior processes, the boundaries of linguistic phenomena are to be modeled as both static borders and fuzzier frontiers in order to represent linguistic processes accordingly. As 'merge' can only take place where two linguistic phenomena—i.e., the people—exchange, and have a common boundary, there are regions where such an exchange cannot take place. Hence, even parts of a common boundary of two linguistic regions are static, due to their nature of a natural barrier.

4.4 Modeling of Linguistic Phenomena with Crisp and Indeterminate Boundaries Over Time

To represent linguistic processes in a computer system, the authors attempt to model them in a functional manner. Thus, the definition is not aligned to a specific system or product. Here we utilize F# (Hansen and Rischel 2013) as functional language to describe boundaries of language phenomena.

In this paper, we restrict ourselves to selected parts of the code that foster the understanding of the modeling of crisp and fuzzy boundaries. First, boundaries of any two-dimensional linguistic phenomena are constructed as lines, which themselves consist of points. Subsequently, the boundaries of the polygons of linguistic phenomena consist of lines. If the line—as part of a boundary—has a fuzzy border, we add a polygon denoting the region of the transition zone—i.e., a fuzzy area. Clearly, the line has to be inside the polygon denoting the fuzzy area.

To model the transition zone between two neighboring language phenomena, two membership functions for each phenomenon are defined. These functions are applied to the two dimensional space with their x-axis perpendicular to the boundary line, and their y-axis showing the fuzzy membership value for each x value. In order to maintain a smooth transition, the fuzzy membership functions are normalized with respect to the maximum width of the transition zone, perpendicular to the boundary line. Hence, this allows the calculation of the membership value for each point within the transition zone. The membership value is then a function, depending on the normalized distance—of the evaluation point from the boundary line—and the fuzzy membership function. The underlying principle is depicted in Fig. 13.

To support the temporal dimension with this approach requires storing the polygons of each language phenomenon, the polygons of fuzzy transition zones, and the according membership functions for each time slice. Hence, genesis of linguistic processes can be analyzed.

5 Real-World Examples of Spatial-temporal Change of Linguistic Phenomena

In the previous sections, we have elaborated on spatial-temporal linguistic processes and their spatial-temporal representation. In detail we focused on the type of boundaries necessary for an accurate representation. In this section, we elaborate on

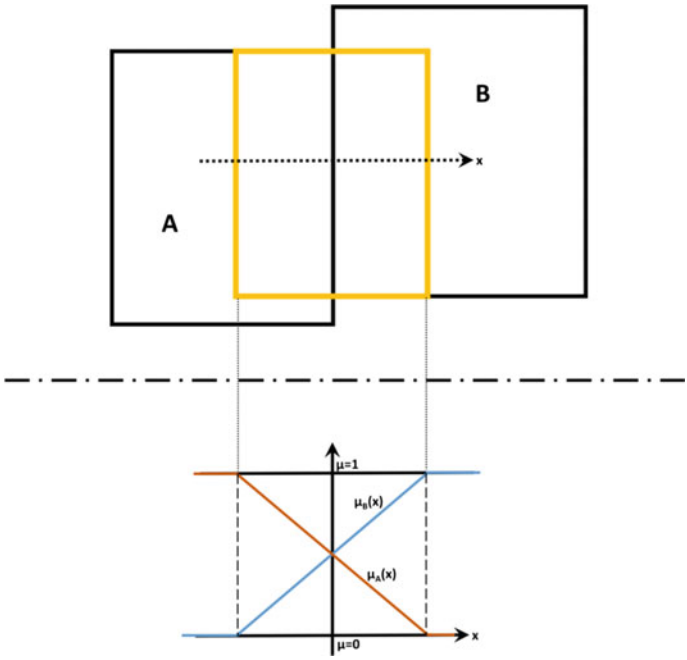

Fig. 13 Schematic graphic of the implementation of fuzzy boundaries. Here two linguistic phenomena A and B are mapped. The *yellow rectangle* denotes the transition zone between A and B. The fuzzy membership function for linguistic phenomenon A is denoted as function $\mu_A(x)$ in *red color*, and for linguistic phenomenon B as $\mu_B(x)$ in *blue*. The fuzzy membership functions are applied with their x-axis perpendicular to the border between A and B. The fuzzy membership value μ denotes the probability of the position to be either part of A or B

some real-world examples to stress the necessity for an accurate spatial-temporal representation with an appropriate boundary definition. These historical processes are not related to modern shifts in language phenomena—especially influences by mass media on language. Nevertheless, they underpin the fact that language is a dynamic process. Additionally, these examples show that language phenomena have both crisp and indeterminate boundaries.

The first example is located in the Paznaun valley. This valley is leading south-west from Pians (850 m) to the Bielerhöhe (2036 m), a mountain pass at the border separating the Austrian provinces of Vorarlberg and Tyrol. The example highlights the creation of a new language phenomenon, moving frontiers and the solidification of the boundary along the Arlberg mountain ridge (Wandl-Vogt 1997; Birlinger 1890). In the years 100–1350, Roman shepherds settled temporarily in the Paznaun, which is still recognizable by a number of roman remains in the dialect of that region. From 1350 until 1850, the Walser gradually moved from the west into the Paznaun, which moves the Alemannic-Bavarian language boundary to the east (across the Arlberg!) and brings an end to the roman dialects in the Paznaun. Around 1850 until 1900, the people in the region oriented their trade channels

towards the east, which resulted in a vital exchange with Bavarian speakers (maybe induced by the opening of the transalpine Arlberg railway). Thus, the language in the Paznaun switched to Bavarian and the Alemannic-Bavarian boundary was moved 'back' to the Arlberg mountain ridge. From 1900 until today, the border is regarded as stable.

Migration processes often induce the end of a linguistic phenomenon, where people with another dialect/language settle in an area—similar to the Paznaun example mentioned above—but also due to political/administrative reasons. One example would be the historical region of Bohemia (today Czech Republic), where historically speakers of Bavarian dialects were found (e.g., Ehrismann and Carolinum 1996). Due to political and administrative reasons, which are not subject of this paper, the Bavarian dialect-speaking inhabitants disappeared, which results in the end of the language region.

Another example that we highlight in this paper are political heritages that are still visible in dialects today. Upper Austria, a province of Austria, was compiled of several princedoms over centuries (see Fig. 14).

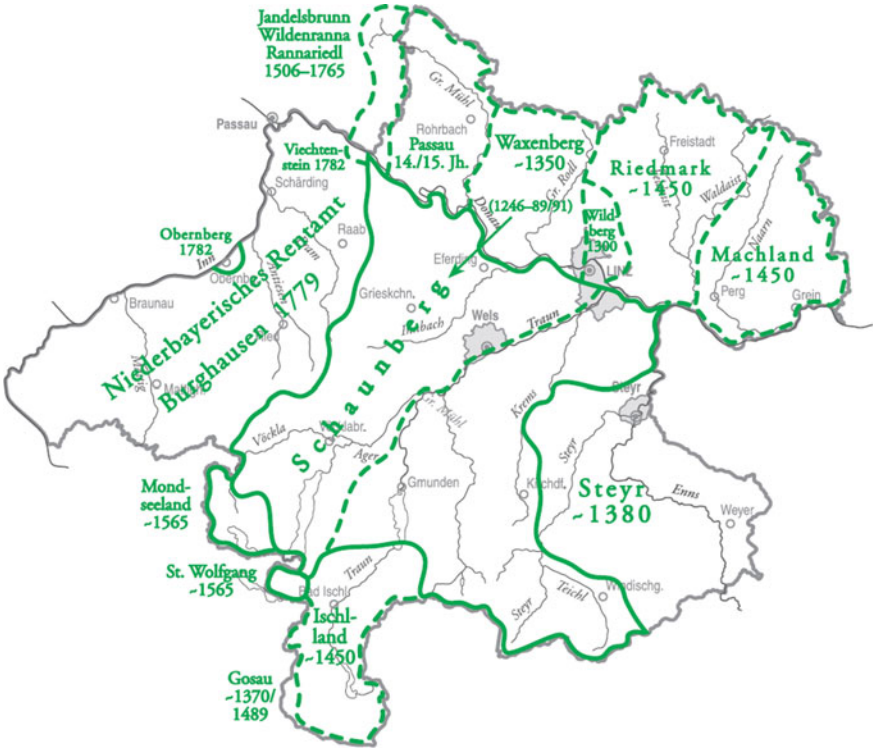

Fig. 14 Historical map of the princedoms of upper Austria and the year they "joined" upper Austria (Wiesinger 2001)

The linguistic distribution of the concept "last year" refers to the main linguistic types "fert", "ferten" and "voriges Jahr". In comparing more recent data (investigation ~70es) with data collections of the 30es an 60es there seems to be some correspondences with the political map (see Fig. 14; Geyer 2001) and shows some analogies with the historic map of Upper Austria (see Wiesinger 2001). Certain forms seemed to be significantly more used in certain administrative, political regions. This is still true for the recent data (70es) and this theory is strengthened by comparison with older data collections (e.g. Datenbank der bairischen Mundarten in Österreich).

Concluding, on this example it can be said, that the princedoms of Upper Austria seem to have relevant impact on linguistic distribution which is still recognizable in recent language. Based on more digital lexical resources, a subsequent spatio-temporal analysis, further research on the process of linguistic development over time and its social interconnections and dimensions are possible (Fig. 15).

6 Conclusion and Discussion

This paper analyzed the spatial-temporal behavior of linguistic/dialect regions and phenomena, and elaborated on the spatial-temporal representation of linguistic processes. In order to model linguistic regions and their spatial-temporal changes accordingly, the authors analyzed the term boundary with respect to the "application area" linguistics. Thus, a boundary can have a different nature—defined on the continuum between border and frontier. Borders and frontiers are the opposite extremal points of the continuum of boundaries, where borders are static, interrupt the exchange between people and separate two regions. Frontiers, on the other hand, are boundaries that have a porous character, and enable the exchange between neighbors. Due to the 'openness' of frontiers the exact boundary line cannot determined, and is of fuzzy nature. Hence, fuzzy theory can be employed to model the transition zone or borderland between two neighboring regions.

An analysis of the linguistic regions of Styria concerning their landform, collected by the dboe@ema Project (Wandl-Vogt et al. 2008; Scholz et al. 2008) shows that ridges, upper slopes as well as plains and valleys form the boundaries of linguistic regions. If we assume that natural barriers hinder the movement and exchange of people, we conclude that mountain ridges and upper slopes show characteristics of static borders. Due to the fact that people are moving through valleys and plains, they exchange language which leads to the conclusion that such landforms can be regarded as frontiers. Thus, the argument that a linguistic region or phenomenon may have both boundary types—borders and frontiers—is supported.

From an analysis of the spatial-temporal processes of linguistic/dialect regions or phenomena—i.e., emerging, ending, moving and merging—the authors argue that each process shows the necessity of modeling linguistic regions with borders and frontiers. Especially frontiers are an appropriate concept to represent the borderland where neighboring regions mix. In order to model the boundaries from a mathematical viewpoint fuzzy set theory (Zadeh 1965) seems appropriate.

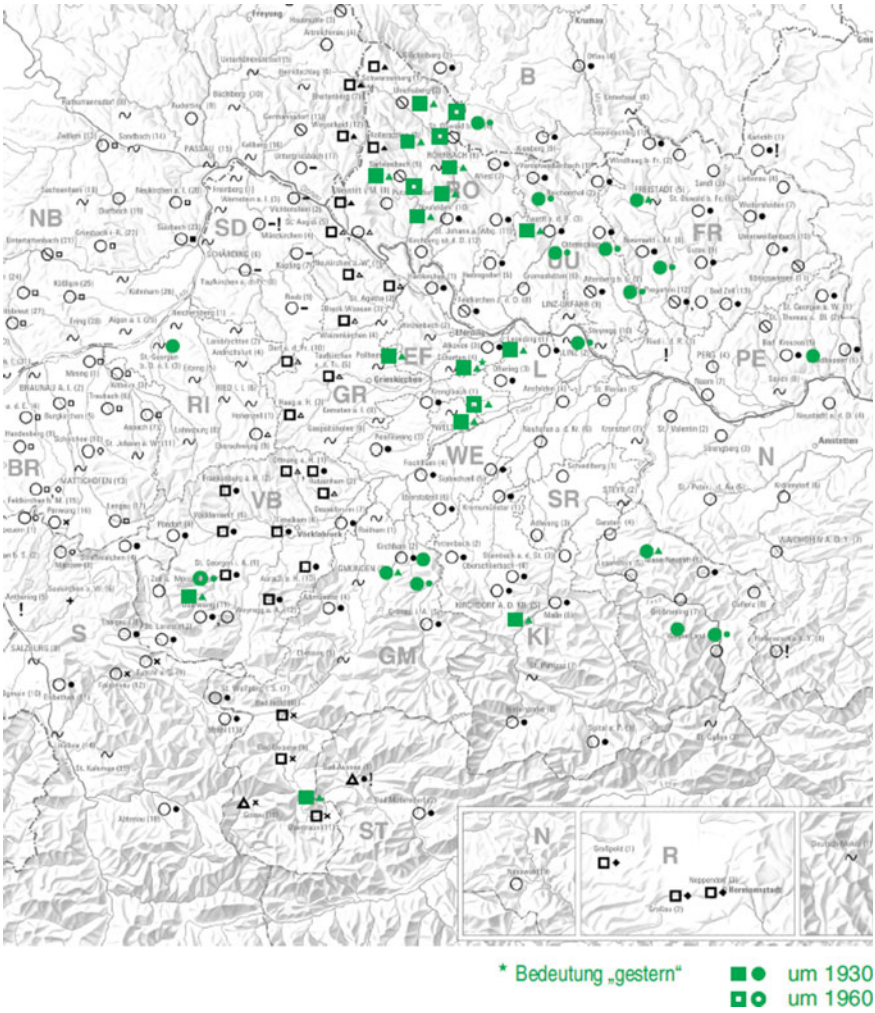

Fig. 15 Linguistic Map presenting the distribution of the word "fert" for "last year": *black symbols* show spatial distribution in the 70es of the last century, whereas *green symbols* present spatial distribution in the late 30es (*filled*) or the early 60es (*blank*) of the last century (Geyer 2001)

Future research items include a definition of the fuzzy theory covering borders and frontiers for the application area linguistic/dialect regions. As linguistic regions change slowly but constantly, there is a need to store the crisp/fuzzy boundary information over space and time, which is solved here with time slices and fuzzy membership functions within a defined transition zone. Furthermore, the approach needs a stronger integration with spatial-temporal processes of objects described by e.g. Hornsby and Egenhofer (1997, 2000) or Claramunt and Theriault (1996).

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