Visualization Schemes for Spatial Processes

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Summary

The visualization of spatial data has a long tradition in the fields of cartography and geographic information science. There are guidelines for the visualization of topographic and thematic data. Dynamic spatial processes, which are becoming important for the development of geographic information systems (GIS), demand visualization guidelines for processes. The objective of this paper is to find an assignment of dynamic visualization schemes, i.e., animations and dynamic symbols like arrows, to types of processes. Our means to identify the types of processes, which are the basis of this investigation, is the theory of partial differential equations (PDEs). This approach reveals three main types of processes: diffusion-like, wave-like, and steady-state processes. Our results show that for selecting an appropriate visualization schema we need to know whether the process changes over time and what kind of object the process affects.
Keywords: dynamic visualization schemes, spatial processes, partial differential equations

1 Introduction

Maps, which are means for representing spatial data and their relationships, have a long history and are widely used. We concentrate here on thematic maps that display quantitative and qualitative data in relation to their location. The guiding principle for cartographers in the production of maps is the readability of the resulting map. Cartographers therefore know minimum sizes of symbols for different scales, the appropriate use of colors, how to generalize, etc. Compared to the theory of the visualization of dynamic processes and the production of dynamic representations, the theory of static representations is well-tested.

This paper builds upon guidelines related to the representation of static thematic data and searches for similar rules for the visualization of spatial processes. In the case of thematic data, the scale of measurement of data (STEVENS 1946) determines which graphical variables (BERTIN 1982) can be used. We are looking for an assignment of types of spatial processes to dynamic visualization schemes. A dynamic visualization schema can either be an animation or a static representation of change by, for example, arrows. We use the theory of partial differential equations (PDEs) to identify types of spatial process. PDEs are commonly used for modeling continuous physical phenomena. The theory of PDEs classifies processes into three main types: diffusion-like, wave-like, and steady-state processes. These three types of processes are the basis of the investigation in this paper.

The results of our investigation show that the classification of spatial processes presented here leads to general comments on the applicability of dynamic visualization schemes. The applicability of a visualization schema for representing a process depends mainly on whether time is included in the process and whether the process affects points or polygons.

The structure of this paper is a follows: In section 2 the guidelines for the use of graphical variables are presented, which provide the background for our investigation. Section 3 discusses the types of processes and the dynamic visualization schemes considered in this paper. Section 4 presents the assignment of visualization schemes to the types of processes together with examples. The results are discussed in section 5 and conclusions drawn in section 6.

2 Graphical Variables and Scales of Measurement

The idea of this paper originates from the definition of graphical variables and their assignment to the scales of measurement, which became a guideline for the production of thematic maps. This section outlines this guideline forming the background for our investigation. In the remaining sections we try to find similar rules for the assignment of visualization schemes to types of spatial processes.

BERTIN (1982) worked on the semiotics of graphical representations and investigated how data listed in tables can be visualized in order to reveal relations between the data sets. He defined graphical variables for the encoding of information in a diagram or map with points, lines, and polygons. These graphical variables are:

- shape,
- hue,
- texture,
- lightness,
- size,
- orientation.

The thematic data that are visualized by the use of these graphical variables belong to one of the following scales of measurement: nominal, ordinal, interval, ratio (STEVENS 1946). In cartography the interval and ratio scales are sometimes combined and referred to as numerical or quantitative data (cf. ORMELING 1996). The scales of measurement define which statistical operations can be applied to data sets and which graphical variables are appropriate for their representation (Table 1).

Tab. 1: Graphical variables that are well suited for representing nominal, ordinal, and numerical data (cf. MACEACHREN 1995, p.279).

	Nominal	Ordinal	Numerical
Shape	✓		
Hue	✓		
Texture	✓		
Lightness		✓	
Size	✓	✓	✓
Orientation	✓		

There are several extensions to Bertin's graphical variables as indicated in (MACEACHREN 2001). One extension deals with dynamic representations that have other requirements regarding the display of information than the representations discussed by Bertin. The list of dynamic graphical variables consists of (DIBIASE, MACEACHREN et al. 1992 as cited in MACEACHREN 1995; MACEACHREN 1995):

- Duration: time span in which an object is visible during an animation.
- Rate of change: relative change of an object compared to the duration of each scene.
- Order: arrangement of the frames in the animation. In temporal animations the order is usually chronological.
- Display date: time or moment in which an object changes in an animation.
- Frequency: rate of appearance of objects, for example when objects are blinking.
- Synchronization: synchronous display of two or more phenomena in order to reveal temporal relationships.

The dynamic graphical variables have to be taken into consideration when developing an animation. Their suitability for the representation of different kinds of data is a topic of research in cartography. MACEACHREN (1995, p.288) provides a table indicating which dynamic graphical variables can be used for displaying quantitative, ordinal, and nominal static data. KÖBBEN and YAMAN (1996) performed subject tests on the perception of the dynamic graphical variables in relation to the perceptual properties association, order, quantity, and selection.

3 Spatial Processes and Their Visualization

This section introduces the subjects of our investigation: types of spatial process and visualization schemes for the display of processes. The types of processes are identified on the basis of partial differential equations. The visualization schemes include different kinds of animations and dynamic symbols.

3.1 Types of Spatial Processes

A wide range of spatial processes exists that happen on different spatial and temporal scales and are analyzed by different domain experts. Examples for spatial processes are the spread of genetic information via pollen dispersal (RICHTER and SEPPELT 2002), urban sprawl modeled with aerial imagery (SHAW and XIN 2003), and the spread of diseases (NEWMAN 2002).

The objective of ongoing research is to identify types of spatial processes that occur repeatedly in space related problems (HOFER 2007). The focus of this research lies on identifying the characteristics of processes that describe how the processes function on a general level. Hofer’s approach is to classify spatial processes by types of partial differential equations (PDEs). PDEs have a long history in the field of mathematical physics. Many computer-based analyses and simulations of continuous phenomena like electromagnetic waves and sound signals are based on PDEs (PRESS, FLANNERY et al. 1986).

In the theory on second order, linear PDEs three types of equations are distinguished: parabolic, hyperbolic, and elliptic equations. These equations show different characteristics and their solutions behave differently. The equations can be assigned to three types of processes (LOGAN 2004):

a) Diffusion-like processes: diffusion-like processes are modeled with parabolic PDEs. Parabolic equations are evolution equations, which means that they show how a process evolves over time (LOGAN 2004). Diffusion describes the random motion of particles, which, in general, disperse from high to low concentrations of particles. Examples for diffusions are the spreading of heat in a metal bar and the spreading of diseases.

b) Wave-like processes: wave-like processes are modeled with hyperbolic PDEs. Wave-like processes occur for example in electromagnetism and acoustics. Hyperbolic equations are evolution equations like parabolic PDEs. One representative of the group of wave-like processes – on which we focus here – is the advection process: Advection is a term from biology for describing the bulk movement of particles in some transporting medium like particles dissolved in a quickly flowing river that are carried downstream. Other terms referring to this kind of process are convection and transport (LOGAN 2004).

c) Steady-state processes: steady-state processes are modeled with elliptic PDEs. These equations do not contain a time variable, i.e., they are equilibrium equations, which makes them different from the other two kinds of equations (LOGAN 2004). They model processes that represent steady-state flows in fields, i.e., there is a balance between input and output in the systems. Examples for steady-state processes are the flow of groundwater and the electric potential in a certain region with fixed boundary conditions.

The classification of spatial processes based on PDEs presented here is of general nature. The idea of looking at spatial processes from the PDE side is to identify the characteristics of certain types of processes. The long-term objective of this work is to provide the basis for extending geographic information systems (GIS) with elementary functionality for dealing with processes (HOFER 2007).

BLOK (2000) looks at spatial phenomena from a different perspective. She concentrates on the visual changes on maps introduced by spatial phenomena and identifies three concepts that describe change in the spatial domain: appearance/disappearance, mutation, and movement. Her objective is to couple the concepts and describe the whole life cycle of events like tornados from appearance to disappearance (BLOK 2000).

For the remaining discussion our focus is on the coarse level of detail related to the three types of processes diffusion-like, wave-like, and steady-state. We differentiate three cases of diffusion and advection processes; these three cases indicate which type of object – a point, a line, or a polygon – is affected or changed by the process. This subdivision according to the types of objects does not apply for steady-state processes, because they affect fields and not single objects. The list of spatial processes we will consider for the assignment of visualization schemes contains:

- Diffusion of points
- Diffusion of lines
- Diffusion of polygons

– Advection of points
– Advection of lines
– Advection of polygons
– Steady state processes

3.2 Visualization of Processes

Our motivation for looking at the visualization of spatial processes is the lack of guidelines for the appropriate display of types of processes. The use of visualizing processes is expressed by BATTY, STEADMAN, et al. (2004, p.1): "…patterns and processes of any complexity can be better understood through visualizing the data, the simulations, and the outcomes that…models generate". EMMER (2001) defines three uses of representing temporal spatial data: presentation of facts, confirmation of a hypothesis, and exploration of data in order to find structures.

Our objective is to find a link between types of spatial processes and appropriate dynamic visualization schemes. A dynamic visualization schema can be either:

a) a set of graphical representations that are changing in time to represent the processes, i.e., animations (Fig.1a) or
b) a static visualization schema for process visualization, where the changes are abstracted to a simple static representation by so-called dynamic symbols (Fig.1b).

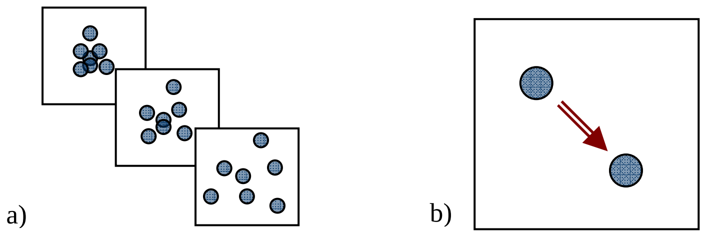

Fig. 1: Dynamic visualization schemes: a) animation of the diffusion of points, b) a static visualization of movement with a dynamic symbol.

Animation is the main tool for representing processes in computer environments. They "…not only tell a story or explain a process, they also have the capability to reveal patterns, relationships or show trends which would not be clear if one would look only at the individual maps" (KRAAK 1999, p.173). The effects of animations, their suitability to represent change, guidelines for their use, etc. are currently researched by cartographers (KRAAK 1999; EMMER 2001).

There are two big groups of animations namely temporal and non-temporal animations. Temporal animations show, for example, how the weather changed during the last week. They represent changes in spatial data regarding locations or attribute values. Non-temporal animations can be successive build-ups of landscapes or flights over an area (KRAAK and KLOMP 1995; KRAAK 1999). KRAAK (1999) subdivides animations into time series, successive build-ups, and changing representations. In addition to animations we investigate static visualizations with dynamic symbols like arrows. These tools are discussed subsequently based on explanations give in (KÖBBEN and YAMAN 1996; KRAAK 1999):

- Time series: Time series belong to the group of temporal animations. The frames of the animation are shown in chronological sequence and represent changes of locations and/or attributes of data. The time units can vary from seconds to years depending on the topic. Examples: life cycle of a tornado, weather of the last day, growth of cities, etc. Map series are the static analog of time series.

- Successive build-ups: Successive build-ups are non-temporal animations keeping the moment in time fixed. They can be used to display different layers of a phenomenon sequentially or to highlight different value classes of a thematic map one after the other.

- Changing representations: Changing representations are non-temporal animations that allow the exploration of data sets. The location and attributes of objects and the time are fixed. Examples are maps with blinking symbols that highlight some objects or flights through landscapes.

- Dynamic symbols: In addition to the animation tools, so-called dynamic symbols offer a possibility to indicate change on a single static map. An arrow can represent movement and lines that are comparable to contour lines, can represent the location of a phenomenon in the course of time (KÖBBEN and YAMAN 1996).

4 Visualization Schemes for Spatial Processes

In section 3 we introduced types of spatial processes and dynamic visualization schemes. The objective of this paper is to find an assignment between the dynamic visualization schemes and the types of processes. Before we summarize this assignment in Table 2, we illustrate the use of application schemes for spatial processes in some examples.

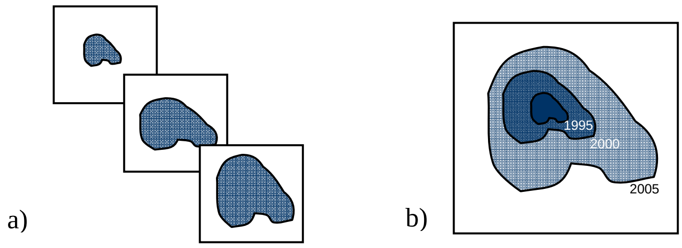

Fig. 2: Dynamic visualization schemes for a diffusing polygon: a) time series, b) lines indicating the expansion of an object.

The use of time series and dynamic symbols for the representation of diffusing points respectively a moving point was already presented in Fig. 1. A real world example fitting to this representation are bacteria growing in a tube. Fig. 2 shows how the diffusion of a polygon could be depicted with time series and lines that indicate the boundary of an object like the outline of a city in the years 1995, 2000, and 2005. Fig. 3 contains a representation of the advection of points; the dynamic visualization schemes for polygons in an advection process are comparable. The advection of points occurs, for example, when a swarm of insects moves from one place to the next. We could understand crop rotation in agriculture as advection of polygons over a period of several years. There are no representations of lines in diffusion or advection processes, because linear objects do not seem to be affected by these processes.

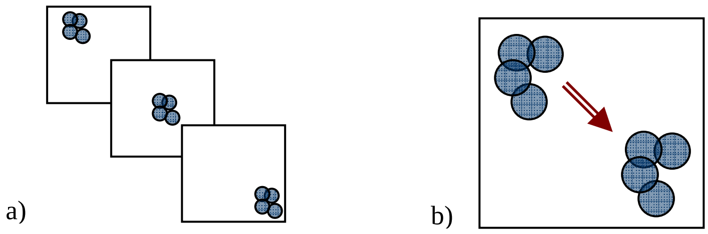

Fig. 3: Dynamic visualization schemes for the advection of points: a) time series, b) static representation of change with a dynamic symbol.

An example for a steady state process is groundwater flow. Groundwater is found under the surface in so called aquifers. Aquifers are water-bearing rocks or soils; the depth in which the aquifers are fully saturated with water is called water table. This water table can be described as a steady-state process, because it remains unchanged, with constant inflows and outflows, over long time periods. Fig. 4 shows a simplified display of a groundwater flow system. When dealing with such a phenomenon a successive build up and a changing representation support its exploration and understanding. It becomes apparent that steady-state processes are essentially different from diffusion and advection processes.

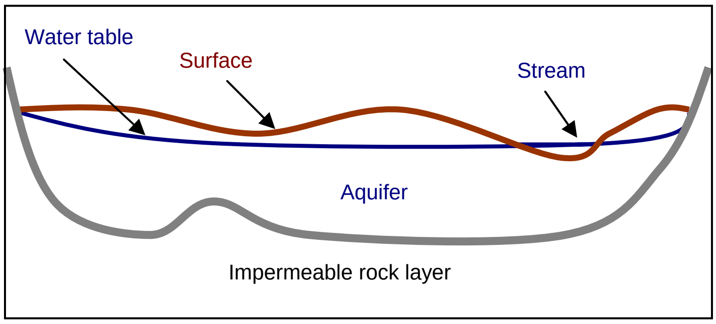

Fig. 4: Groundwater flow as an example for a steady state process.

The assignment of visualization schemes to the list of spatial processes is presented in Table 2. The diffusion and advection of lines do not contain check marks, because diffusion and advection processes do not change linear objects at the level of detail considered.

Tab. 2: Dynamic visualization schemes assigned to types of spatial processes.

Process / Visualization schema	Time series	Successive build up	Changing representations	Dynamic symbols - arrows	Dynamic symbols - lines
Diffusion of points	✓			✓	
Diffusion of lines					
Diffusion of polygons	✓				✓
Advection of points	✓			✓	
Advection of lines					
Advection of polygons	✓			✓	
Steady state process		✓	✓		

5 Results

The basis for the investigation of dynamic visualization schemes for processes was a list of spatial processes. This list originated from a classification of spatial processes into diffusion-like, wave-like, and steady state processes. The list of processes contains the diffusion of points, lines, and polygons, the advection of points, lines, and polygons, and steady state processes, which affect fields. The dynamic visualization schemes we considered in this paper are time series, successive build-ups, changing representations, and dynamic symbols.

The main outcome of this paper is the assignment of dynamic visualization schemes to spatial processes presented in Table 2 (see Section 4). This table shows that:

- Time series seem to work for any process representing change over time.
- Successive build-ups and changing representations are less useful for time-dependent processes, because time is fixed in both visualization schemes.
- A steady state process can be explored by successive build-ups and changing representations.
- It is important to differentiate the type of object affected by a process. The visualization schemes for points and polygons may differ.
- Statements concerning the visualization of linear features affected by diffusion or advection were omitted. There seems to be no representative example for lines being affected by these processes at the level of detail considered.

These outcomes show that the classification of spatial processes presented in this paper, can help to make general comments on the applicability of dynamic visualization schemes. We consider these results as a starting point for the definition of guidelines related to the visualization of spatial processes.

6 Conclusions and Future Work

The hypothesis of this paper was that the type of process influences the applicability of visualization schemes for its representation. The types of processes were identified on the basis of partial differential equations, which resulted in a coarse classification of processes into diffusion-like, wave-like, and steady-state processes. The results of our investigation show that even this coarse classification of spatial processes allows us to make general comments on the use of dynamic visualization schemes.

Our future work will be concerned with refining the list of spatial processes and finding subtypes of processes in the three main groups of processes. We hope to thereby achieve a more detailed analysis of dynamic visualization schemes. In this work we focused on advection and diffusion processes leading to changes in the locations of objects. We have to investigate, if the assignment of visualization schemes changes when we consider the processes in the sense of starting from points, lines, or polygons and affecting the area around the objects.

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