Composing Models of Geographic Physical Processes

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Abstract. Processes are central for geographic information science; yet geographic information systems (GIS) lack capabilities to represent process related information. A prerequisite to including processes in GIS software is a general method to describe geographic processes independently of application disciplines. This paper presents such a method, namely a *process description language*. The vocabulary of the process description language is derived formally from mathematical models. Physical processes in geography can be described in two equivalent languages: partial differential equations or partial difference equations, where the latter can be shown graphically and used as a method for application specialists to enter their process models. The vocabulary of the process description language comprises components for describing the general behavior of prototypical geographic physical processes. These process components can be composed by basic models of geographic physical processes, which is shown by means of an example.
Keywords: geographic physical processes, process modeling, process language, GIS

1 Introduction

Geography is investigating distributions of objects, people, goods, etc. in space [2]. Distributions are subject to change, which is caused by processes. Getis and Boots define spatial processes as "tendencies for objects to come together in space (agglomeration) and to spread in space (diffusion)" [11, p.1]. Examples for processes of interest in geography are the migration of people, the spread of diseases, the movements of goods, the flow of water, the transport of sediments, etc. [2,5]. Spatial processes are also studied in disciplines like biology, ecology, hydrology, economics, etc. Numerous approaches for process modeling have been developed and implemented in specialized modeling tools. The knowledge of professional modelers is considerable and models are becoming increasingly realistic and complex. The goal of modeling applications is generally a prediction of effects of processes.

Geographic information systems (GIS), the tools used in geography, play a supportive role for process modeling; they are mostly used for data management and for visualization of results calculated by modeling tools. The interoperation between GIS and modeling tools is hindered by a lack of capabilities to represent process related information on the GIS side. The integration of time and process in GIS is one of the unsolved issues of geographic information science [20,7,12].

The integration of sophisticated process modeling capabilities that address the specialized methods of the different models is impossible. Instead, GIS need to be complemented with a basic ability to represent processes in order to enhance the interoperability with process modeling tools. A first step towards GIS with process handling capabilities, requires the identification of prototypical process behaviors across disciplines. A second requirement is the development of a general method to describe geographic processes and to compose process components to models. Our proposal to meeting these requirements is a *process description language* for geographic physical processes (section 3). The hypothesis of our work is that mathematical languages can be used for describing and composing models of the general behavior of geographic physical processes.

A fundamental requirement for a process description language is the identification of a vocabulary that allows entering the particularities of processes. The focus of the proposed process description language is on the description of the general behaviors of geographic physical processes. The restriction to geographic physical processes, which are a subset of physical processes, allows the reuse of existing knowledge on physical process modeling (section 2). Physical models can be formulated in mathematical languages such as (partial) differential equations. An analysis of basic partial differential equations lead to the identification of prototypical processes (section 4). The contribution of the process description language is the linkage between mathematical formulations of prototypical process behaviors and concise examples of geographic physical processes. For this purpose processes are conceptualized as block models, which are expressed with difference equations (section 5). Block models have the advantage that they can be graphically depicted for supporting the modelers at their task. The application of the process description language to modeling and composing process models is shown by means of an example (section 6).

2 Geographic Physical Processes and GIS

Processes are sequences of events that are connected by a mechanism; they lead to a recognizable pattern [11,28]. The mechanism may be initiated by different kinds of forces such as physical, social, or political forces [11]. *Geographic* or *spatial* processes are processes that shape distributions of elements in space; they create spatial structures.

Geographic processes can be social or physical processes, which are two ontologically different groups of processes [10]. Modeling applications using geographic information systems (GIS) show an emphasis on environmental, i.e., physical processes [4]. We consider physical processes that are of interest in geography, geographic physical processes, a good start for developing a process description language.

An example for a geographic physical process is the dispersion of exhaust fumes of a factory. The question of interest in relation to this process is where the areas are that are most affected by the exhaust fumes [32]. In order to answer this question, the spreading of the exhaust fumes in the atmosphere has to be modeled. From the moment the exhaust fumes are released to the air from the factory's chimney, they spread continuously and are moved by air currents. The exhaust fumes affect the air quality in a region surrounding the factory. A model of this process is discussed in section 6. Other examples for geographic physical processes are water runoff, groundwater flow, sediment transport, and hill slope erosion.

Geographic physical processes are a subset of physical processes and share their characteristics. From an ontological point of view, physical processes are subject to material causation in contrast to social processes that are following information causation [9]. Information causation acting in social processes is not limited to temporal or spatial neighborhood. In case of material causation the energy transmitted from one unit to the next corresponds to the gain of energy in the receiving unit. This conservation of energy or some other property like mass is a common principle of physical processes. Physical processes establish the physical reality, which is continuous [13]. In addition, physical processes are considered to be local processes; this means that their influences are restricted to the neighborhood. The spectrum of interest in geography "excludes quantum or relativistic effects and is thus rigidly Newtonian" [12, p.1].

The integration of processes in GIS is a longstanding question of geographic information science [20,7,12]. A key difficulty regarding the integration of GIS and process models is the static nature of GIS. Kavouras [19, p.50] recognizes in GIS a "... lack of a concrete theoretical foundation, which among others, has not found acceptable ways to represent generically data, processes, and data on flows and interactions associated with socio-economic applications". There are reasons to integrate process models and GIS, despite all conceptual differences [4].

Various approaches have been presented aiming either at extending GIS with time [20,17,35] or at integrating process models in GIS [33,36,29,34]. Time-oriented approaches generally focus on objects and their change [17,35]. Theories developed from this point of view are not generally applicable to geographic physical processes, because they are continuous processes with field-like characteristics. Work by Yuan [36] refers to phenomena with both, object and field characteristics, and applies to the analysis of rainstorms. General approaches for integrating geographic phenomena in GIS are, e.g., PCRaster [33], the vector map algebra [34], and the *nen* data model [28,29].

The integration of process models in GIS is referred to as embedded modeling in GIS. Three other levels of integration of modeling tools and GIS are differentiated, which are: loose coupling, tight coupling, and modeling tools integrating GIS functionality [30,4,6]. Loose coupling means that GIS are used for generating the input for modeling software and for visualizing the calculated results. The option of tight coupling connects GIS and modeling software through a common interface; this is only achieved for single models. Highly specialized modeling tools may integrate the GIS functionality they require in their system. Mitasova and Mitas [24] additionally mention the group of GIS and web-based models, where widely used models are provided as web applications together with required input data and parameters.

A series of applications are implementing the integration of GIS and process models on the different levels. The applications are often successful at integrating a particular model of a process from the viewpoint of a certain discipline. In contrast to the focus of these applications, we aim at identifying general functionality required to extend GIS with general process modeling capabilities.

3 Why Develop a Process Description Language?

The potential of GIS regarding the spatial aspects of process modeling and analysis is not yet exploited. We take a look at the requirements of process modeling for identifying areas of improvement on the GIS side. Improving the capabilities of GIS regarding process modeling can lead to a better interoperability between GIS and process modeling tools in the long run.

In the Virtual GIS project [3] criteria for the development of spatial modeling systems have been identified. These criteria include a graphical user interface, a component for the interactive development of scenarios, functionality for spatial analysis and visualization, and "a generic system that operates as a toolbox independent of a specific domain" [8, p.3]. To achieve such a system, we have to abstract from specifics of different disciplines and from details of the quantitative analysis. Our proposal is the development of a *language* to describe and to compose models of prototypical geographic processes; with a restriction to geographic physical processes.

The process description language contributes two things: a) the identification of prototypical processes and b) a method to generally describe and compose models of geographic physical processes. Composition of model components is an important feature for process modeling as previously mentioned by [22,26]. The qualitative description focuses on general principles of processes, which of course does not replace quantitative process modeling. The process description language allows the generation of *qualitative sketch models* of processes describing the general behavior of the processes. These sketch models are created with the language not requiring deep mathematical knowledge. The models can serve as input for existing modeling tools and facilitate process modeling for non-expert modelers.

We see the proposed process description language as a layer on top of existing modeling tools for spatial processes such as PCRaster [33] and the vector map algebra [34]; a layer with a more rigorous mathematical foundation in partial differential equations. The motivation of developing the process description language is an improvement of GIS functionality, which is a distinguishing feature from modeling tools such as the Spatial Modeling Environment (SME) [22], SIMILE [25], or the 5D environment [23] developed in other disciplines than the GIS discipline. In addition, modeling tools developed for modeling primarily non-spatial processes that are based on STELLA can solve differential equations but no partial differential equations.

4 A Mathematical Model and Prototypical Processes

"Process models generally express theories predicting the nature of the exchange of energy and mass within systems, over time" [27, p.361]. A model of a physical process comprises a configuration space, interactions between the elements of the configuration space, governing equations and constitutive relations [15]. The configuration space contains information about the elements of the modeled system together with physical parameters, initial and boundary conditions, etc. The interactions between the elements of a system are related to governing equations. The governing equations of physical models are based on natural laws. Constitutive relations are required to fully describe the model of the process. The practice of process modeling is well summarized in the following statement: "Because of the complexity of the Earth systems, process-based modeling of geospatial phenomena relies in practice on the best possible combination of physical models, empirical evidence, intuition and available measured data" [15, p.2].

The governing equations of physical phenomena are based on natural laws that generally refer to the conservation of a property such as mass or energy [16]. Fundamental conservation laws state that the total amount of, e.g., mass in a system remains unchanged. The amounts of a quantity going in, going out, and being created or destroyed in a region, have to correspond to the amount of change in a certain region [21]. The general conservation law consists of three main components: the component specifying the change of the concentration of a substance $u(x,t)$ over time, the flow of the substance $\phi(x,t)$, and sources or sinks in the system $f(x,t)$. The specification of these three components is sufficient for describing the general behavior of a series of physical phenomena [21]:

$$\frac{\partial u(x,t)}{\partial t} + \frac{\partial \phi(x,t)}{\partial x} = f(x,t)\,. \qquad (1)$$

Equation 1 is a general conservation law in one spatial dimension formulated as a partial differential equation (PDE). PDEs are one possible mathematical language for formulating models of physical and thus geographic physical processes. A PDE is widely applicable, because "it can be read as a statement about how a process evolves without specifying the formula defining the process" [1].

The terms $u(x,t)$ and $\phi(x,t)$ in Equation 1 are unknowns, when assuming that sources and sinks are given [21]. For describing the unknowns, an additional equation is required: a constitutive relation [21]. These constitutive relations generally define the flow term of the conservation equation. They give a rule to link flow $\phi(x,t)$ and concentration $u(x,t)$ of a substance [16]. The definition of the constitutive relations is based on physical characteristics of the system and often founded on empirical evidence.

Two commonly differentiated kinds of flow, which are described by constitutive relations, are advective flow ϕ_A and diffusive flow ϕ_D. Advection (transport by flow) and diffusion (random spread of particles) are important kinds of processes also for geography. The flow of a substance or object due to advection is specified by Equation 2; the flow of a substance due to diffusion is modeled by Equation 3.

$$\phi_A = u(x,t) * v, \text{ with v...flow velocity}\,. \tag{2}$$

$$\phi_D = -k * \frac{\partial u(x,t)}{\partial x}, \text{ with k...diffusion constant}\,. \tag{3}$$

The flow term ϕ in the conservation equation (Equation 1) is composed of the advective component ϕ_A and the diffusive component ϕ_D:

$$\phi = \phi_A + \phi_D\,. \tag{4}$$

Depending on the process, advective and diffusive components of flow can be present or either of them can be zero. Inserting the constitutive relations describing the flow terms in the conservation law, under consideration of the possible combinations of terms, leads to a series of equations: the advection equation, the diffusion equation, and the advection-diffusion equation.

Advection equation: The advection equation (Equation 5) describes the bulk movement or flow of a substance in a transporting medium [21]. The direction and velocity of flow are determined by the flow direction and velocity v of the transporting medium. The equation is an evolution equation that shows how the process evolves over time. An example for an advection process is the transport of pollen by wind.

$$\frac{\partial u(x,t)}{\partial t} + v * \frac{\partial\left(u(x,t)\right)}{\partial x} = f(x,t) \tag{5}$$

Diffusion equation: The diffusion equation (Equation 6) describes a process where a substance spreads from areas of higher concentrations of the substance or areas with higher pressure to areas with lower concentrations or pressure [21]. Diffusive flow ϕ_D is specified by flow down the concentration gradient, which is expressed by the minus sign in Equation 3. The motion of the particles is random. The diffusion equation is again an evolution equation. An example for a diffusion process is a contaminant diffusing in standing water.

$$\frac{\partial u(x,t)}{\partial t} - k * \frac{\partial^2 u(x,t)}{\partial x^2} = f(x,t) \tag{6}$$

Advection-diffusion equation: In the case of an advection-diffusion process, diffusive and advective flows take place. An example is the spread of a toxic liquid in a lake: the liquid diffuses from areas of higher to those of lower concentrations of toxins and in addition, the water current of the lake moves the toxic liquid. In the case of this process, both types of flows are present in the conservation equation and lead to an advection-diffusion equation (Equation 7).

$$\frac{\partial u(x,t)}{\partial t} + v * \frac{\partial\left(u(x,t)\right)}{\partial x} - k * \frac{\partial^2 u(x,t)}{\partial x^2} = f(x,t) \tag{7}$$

Steady-state equation: Important are also the steady-state versions of the conservation equation, where the term including time is zero ($\frac{\partial u(x,t)}{\partial t} = 0$) and the source is a function of space $f(x)$ [16]. In a steady-state process the available amount of a quantity remains unchanged; what changes is the amount of the quantity occupying a position in space over time. The equation models steady-state flow in fields. This kind of equations is known as equilibrium equation. The following equation (Equation 8) shows the steady-state Poisson equation in two dimensions. The Poisson equation contains a source or sink term, which the second steady-state equation, the Laplace equation, does not contain.

$$\frac{\partial^2 u(x,y,t)}{\partial x^2} + \frac{\partial^2 u(x,y,t)}{\partial y^2} = f(x) \tag{8}$$

The list of equations is usually complemented by the wave equation, which describes the propagation of waves such as sound waves or water waves. The discussion of the wave equation would exceed the scope of this paper and is left for a future report on the topic.

PDEs allow an analysis of process behavior from a theoretical point of view. The identified PDEs provide the core for the establishment of the vocabulary of the process description language. We have to show that the equations modeling prototypical processes can be linked to geographic physical processes. This task is achieved by the process description language.

5 A Process Description Language

The fundamental laws governing the models of geographic physical processes are conservation laws and flow laws. The specification of these laws describes the qualitative behavior of a process. A summary on kinds of processes described by these laws was given in section 4. Additional requirements for the specification of a model of a physical process are the definition of the configuration space including parameters, boundary and initial conditions etc. [15, c.f. section 4]. These aspects of process models are left aside in the work presented in this paper. The focus is on the key task of the process description language: the assignment of the equations modeling general process behavior to a certain geographic physical process.

For the purpose of selecting an appropriate equation for modeling a certain process, we conceptualize geographic physical processes with deterministic block models [32]. Blocks can be aligned next to each other, on top of each other, or on top and besides each other, just as required to represent a process in 1D, 2D, or

3D in the model. This kind of representation is comparable to raster and voxel representations in GIS. Block models are useful for conceptualizing geographic physical processes; they describe the behavior of a process with respect to blocks of finite size. For the specification of the process behavior we define the storage of a substance, the flow of the substance and sources and sinks in the system. We will see that there are geographic physical processes, whose behavior corresponds to the behavior of processes described with the equations from Section 4.

From a mathematical point of view the approach using block models is closely related to finite difference methods. The formulation of the block models is done mathematically with difference equations. Differential and difference equations are seen as equivalent languages for expressing process models. Differential equations are continuous representations of a phenomenon; difference equations are a discretization of differential equations. Linking PDEs to difference equations and vice versa is always possible for the basic, linear equations we are working with. A previous account of the connection between PDEs and difference equations has been given in [14]. The advantage of using blocks for establishing a model is that the model can be visualized.

General conservation laws apply to block models as to continuous representations of phenomena. The formulation of the conservation equation as a difference equation in three dimensions is ($\triangle$ labels a difference):

$$\frac{\triangle F}{\triangle t} + \frac{\triangle \phi}{\triangle x} + \frac{\triangle \phi}{\triangle y} + \frac{\triangle \phi}{\triangle z} = f\,. \tag{9}$$

The change in the density or concentration of a substance F stored in a block over a time interval is expressed by $\frac{\triangle F}{\triangle t}$. This change is caused by flows across the boundaries of a block (e.g., flow in x-direction$\frac{\triangle \phi}{\triangle x}$) and sources or sinks ($f$) in the system [18]. The flow in a model is captured by describing the flow between two neighboring blocks; it is specified by the gradients of the flux terms ϕ in x, y, and z direction. The gradients of the flux terms can either be negative and refer to flows out of a block or positive and refer to flows into a block. Figure 1 shows a block and the flux terms in all directions of the block. $\phi_{x|x}$ refers to the flow across the left border of a block and $\phi_{x|x+\Delta x}$ refers to the flow across the right border of a block in positive x, respectively y and z, direction. The gradient of the flux terms in x-direction, which gives the flow in x-direction, is defined by (Equation 10):

$$\frac{\triangle \phi}{\triangle x} = \frac{\phi_{x|x+\Delta x} - \phi_{x|x}}{\triangle x}\,. \tag{10}$$

The general definition of the flow across a face has to be extended by the specification of the type of flow taking place, which depends on the ongoing process. This means that in Equation 9, the flux terms ϕ have to be replaced by the specific type of flow going on. We discuss here three possible types of flow (c.f. section 4):

- advective flow: $\phi_A = F * v$,

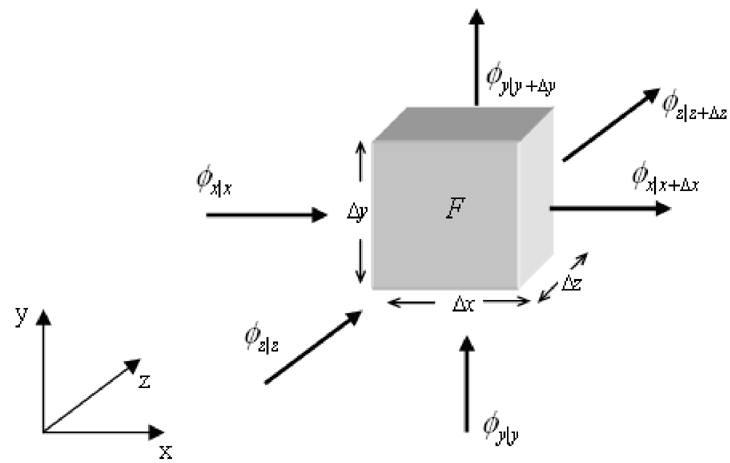

Fig. 1. Flux terms in three dimensions in respect to a block [31].

- diffusive flow: $\phi_D = -k * \frac{\triangle F}{\triangle x}$,
- and advective-diffusive flow: $\phi = \phi_A + \phi_D = F * v - k * \frac{\triangle F}{\triangle x}$.

The outcome of this procedure is a difference equation that describes the general behavior of an ongoing process. The kinds of equations considered in this paper were discussed in section 4. The presented approach produces a language to describe the processes, which so far are missing in a GIS. The language consists of:

1. the state variable (e.g., F) referring to data in a GIS,
2. operations applicable to the state variables (primarily partial differences like $\frac{\triangle F}{\triangle x}$),
3. and multiplicative constants to form
4. equations.

The language has further the important composability property: simpler descriptions can be composed to more complex descriptions. The example in section 6 shows that first, a simple model can be created that considers only diffusive flows; this model can be extended for a component referring to advective flows. Adding diffusive and advective flows gives the total amount of flow in the system.

The description of geographic physical processes resulting from the use of the process description language is qualitative; it can be seen as a *sketch-model* of a process. A detailed quantitative evaluation of processes is not in the foreground of our work. However, because of the formulation of the models with difference equations and the possibility to change to a representation as differential equations, the output of the process description language can serve as input for a quantitative analysis of processes.

6 Composing Process Models - An Example

A strength of the chosen conceptualization of the processes based on blocks is the intuitive approach to composing process models. Adding components and links to existing components extends the model. The illustrative example of a geographic physical process that we model with the process description language is the dispersion of exhaust fumes of a factory (c.f. section 2).

First, we build a simple model that considers the spread of exhaust fumes with density $F(x, y, z, t)$ in the atmosphere and a source $f(x, y, z, t)$ alone. The source term is zero except for the location of the smoke stacks. We omit the influence of gravity.

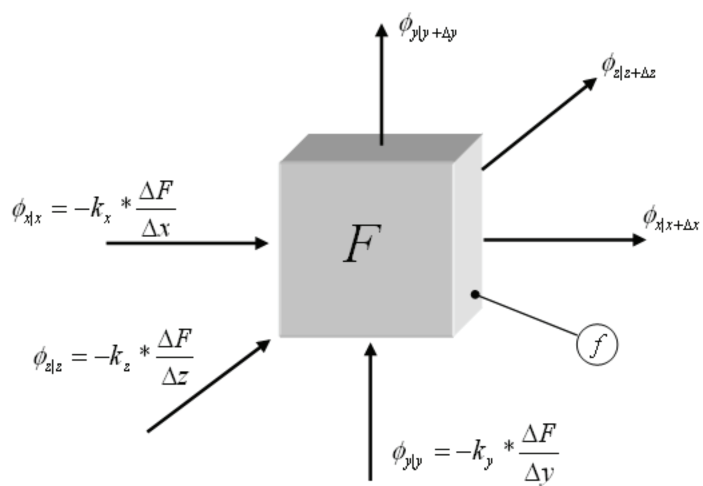

Fig. 2. Diffusive flux terms in three dimensions and source f of fumes.

For the block model we need to specify the storage equation and the flow equation that describe how fumes spread in the atmosphere. We assume that the fumes are homogeneously distributed in each block; the density of fumes in a block is an indicator of the ratio between fumes and air. The storage equation defines the change in the density of fumes in a cell over a time period. The rate of change in the concentration of fumes $\triangle F$ over a time interval $\triangle t$, depends on how much exhaust fumes come in and go out of a block. The flow of fumes in and out of a block is defined by a flow law. We assume that the amount of flow between two blocks depends on the difference in fume concentration between the two blocks; fumes spread from areas of high fume density to areas of lower fume density. This characterization corresponds to the behavior of a diffusion process. The flow taking place is diffusive, the advective component of flow is zero. Figure 2 shows the diffusive flux terms in three dimensions. The diffusive flux term ϕ_D is defined by:

$$\phi_D = -k_x \frac{\triangle F}{\triangle x} - k_y \frac{\triangle F}{\triangle y} - k_z \frac{\triangle F}{\triangle z} \,. \tag{11}$$

Inserting the specification of ϕ_D (Equation 11) in the general conservation law (Equation 9), leads to a diffusion equation (Equation 12). The diffusion equation, therefore, is a model of the spreading of fumes in the atmosphere.

$$\frac{\triangle F}{\triangle t} - k_x \frac{\triangle^2 F}{\triangle x^2} - k_y \frac{\triangle^2 F}{\triangle y^2} - k_z \frac{\triangle^2 F}{\triangle z^2} = f \,. \tag{12}$$

The simple model above omits the influence of air currents that have effects on the distribution of exhaust fumes in the air. Therefore, we add a component referring to air currents with velocities in three dimensions $v = (v_x, v_y, v_z)$ to the model.

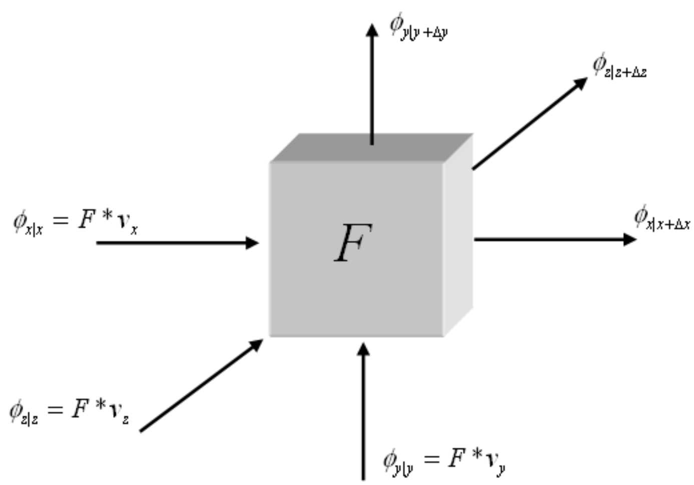

Fig. 3. Advective flux terms in three dimensions describing air currents.

The change in the concentration of fumes in a block consists again of the amount of fumes coming in and going out of a block. Now we have to consider two kinds of flows; the diffusive flow ϕ_D as described above and the movement of fumes by air currents. The movement of fumes by wind depends on the concentration of fumes in a block and the velocity of the wind in x, y, and z direction: v_x, v_y, and v_z. The fumes are transported by the flow field of air currents; this kind of flow is known as advective flow ϕ_A (c.f. Equation 2). Figure 3 depicts the advective flux terms in reference to a block; the mathematical formulation is given below (Equation 13):

$$\phi_A = F v_x + F v_y + F v_z \,. \tag{13}$$

We insert the advective flux term ϕ_A (Equation 13) in the conservation law (Equation 9) to get a model of the effects of air currents on fumes (Equation 14):

$$\frac{\triangle F}{\triangle t} + \frac{\triangle (F v_x)}{\triangle x} + \frac{\triangle (F v_y)}{\triangle y} + \frac{\triangle (F v_z)}{\triangle z} = 0\,. \tag{14}$$

The right side of Equation 14 is zero, because we assume that there are no sources or sinks of air currents in our system. The resulting equation is an advection equation. This equation models the movement of fumes by air currents. To get the complete description of our model that considers the diffusion of fumes and the advection of fumes by wind, we have to compose Equation 12 and 14. We know from Equation 4 that the complete flow in a model consists of the sum of advective flux terms ϕ_A and diffusive flux terms ϕ_D. Combining both types of flows in one equation, leads to an advection-diffusion equation (Equation 15):

$$\frac{\triangle F}{\triangle t} + \frac{\triangle (F v_x)}{\triangle x} + \frac{\triangle (F v_y)}{\triangle y} + \frac{\triangle (F v_z)}{\triangle z} - k_x \frac{\triangle^2 F}{\triangle x^2} - k_y \frac{\triangle^2 F}{\triangle y^2} - k_z \frac{\triangle^2 F}{\triangle z^2} = f\,. \tag{15}$$

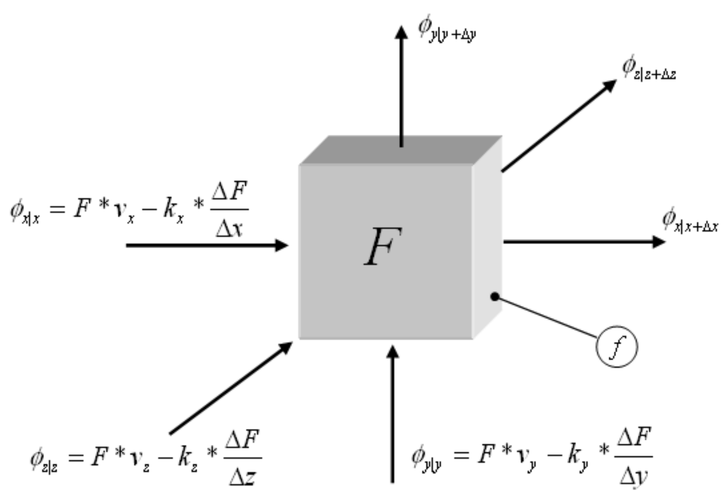

Fig. 4. Total flow in the model of the dispersion of exhaust fumes.

The advection-diffusion equation describes the change in the concentration of fumes in a block under consideration of air currents that move the fumes. Figure 4 shows the total flux terms acting on a block. The modeling process showed that process components can be composed to extend the model of the process. The two kinds of flows taking place in our model of the dispersion of exhaust fumes, can simply be added to give the total amount of flow in the system.

The specification of complete models of geographic physical processes requires the definition of a configuration space, boundary and initial conditions, parameters, etc. (c.f. section 4). Adding this information allows the quantitative analysis of the models with, for example, a finite difference or finite element solver. The focus in this paper was on the storage and flow laws describing the behavior of processes; the definition of the configuration space, required data sets, boundary conditions, etc. that complement a process model, yet have to be added. This additional information about the model is, however, implicitly contained in the model description.

In the future, values for parameters, boundary conditions, and initial conditions could come from the data stored in a GIS. In addition, the solution of the difference equation resulting from modeling the process, could be a GIS layer, which gives the distribution of exhaust fumes over time.

7 Results and Conclusions

Mathematical languages can be used for describing and composing qualitative models of geographic physical processes. Based on an analysis of differential equations we identified equations that model prototypical process behavior. By means of deterministic models based on blocks, the process description language links geographic physical processes with these prototypical process equations. The illustrative example of a model for the dispersion of exhaust fumes from a factory showed how a process is qualitatively described and how process components are composed.

The description of processes on a general level, as achieved by the process description language, can enhance the usability of existing modeling tools for non-expert modelers. The sketch model established with the process description language can serve as input for modeling tools that require the description of the process closer to mathematical details of the model equations.

The presented work lays the foundation for a process enriched GIS. The establishment of a process model in a process enriched GIS, could work as follows: The process description language allows the specification of the general behavior of a process. Data on parameters, initial conditions, boundary conditions, etc. can be derived from data available in the GIS. The process description together with data on initial and boundary conditions, parameters, etc. serve as input for, for example, a finite element solver. The quantitative analysis of the process done with the finite element solver results in a layer in the GIS that represents the ongoing process. A series of questions regarding the usage of process modeling in GIS, the assessment of the suitability of the models, the technical realization, etc. are raised by the idea of a process enriched GIS. In the long run such a GIS could become a comprehensive simulation tool.

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