A Formalization of Spatial Spread

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Abstract

A common form of Spatial Simulation Modeling is the rendering of a process acting over, or objects moving in time or space. No formal description of Spatial Spread exists, leaving those with the need for classification of spread not classified by Spatial Diffusion at a loss. A formalization of Spatial Spread is introduced incorporating the nature of the spread, the temporal characteristics of spread, the forcings of spread, the context of spread, and data and modeling techniques. Examples of real-world spread phenomena are presented, as well as the spatial modeling approaches to those spread processes, along with a classification system that can be used in the linking of spatial models.

1. Introduction

Spatial Simulation Modeling is a growing tool in policy, academia and education because of its ability to create "would be worlds" (Casti, 1997) on a desktop computer in reasonably short periods of time. Such fast rendering of simulations affords the exploration of scenarios of management or environmental alternatives, as well as the experimentation with processes in silico. One important suite of Spatial Simulation Models is spatiotemporal spread models, which have been used to simulate a myriad of processes from human migration to weather to the spread of ideas. This work focuses on describing a framework of spatial spread and an analysis of the data and modeling techniques that can be used for each type of spatial spread.

Spatial spread or spatial diffusion is the generalized term for processes of movement of geospatial entities on the surface of the Earth. Spread occurs at all spatial and temporal scales and in virtually every subject domain. The rise of computer technology has afforded the rendering of spread processes for description and modeling, for forecasting and understanding. Yet there is no formal description of spatial spread processes given the current status of geospatial data, modeling and understanding. In 1981, Cliff created a simple classification of spatial diffusion, yet his work is now outdated and unusable, especially considering the multifaceted nature of spatiotemporal modeling (Cliff, 1981). In an increasingly complex and complicated world, coupled modeling and data fusion is a powerful solution for many modeling and policy challenges. A common conceptualization of geospatial processes will improve the roadblocks inherent in data- and model-sharing. Through a contemporary formalization of spatial spread, spatial modelers will be able to understand the context of their data and models, and how different geospatial simulation models can be coupled together.

2. Components of Spatial Spread

For this work, special spread is defined as the change of the spatial extent of a "geographic entity" over time. A "geographic entity" is a group of discrete objects or the presence of some attribute in discrete objects. Discrete objects are composed of the geographic primitives (points, lines, polygons), and well as objects in a field (object fields) (Cova and Goodchild 2002) or as a combination of spatial and temporal primitives. Intrinsic in a formalization of spatial spread is the understanding that the nature of spatial spread is tied to the sensitivity of the observation, measurement, modeling and understanding of the spread phenomena to the spatial modeler. There are few absolutes in geographic modeling, and spatial spread processes are no different.

There are five major components of spatiotemporal spread. These are:

1) The nature of spread
2) Temporal characteristics of spread
3) Spread forcings
4) Context of spread
5) Data and modeling techniques

The nature of spread is a necessary component in a description of spatial spread because spatial spread does not necessarily imply growth of extent. A spread process can include the shrinking of extent, an oscillation of size, as well as non-contiguous growth. While a real or modeled spread process can be in any of the heretofore mentioned forms of spread, it is the combination of the primitives that characterizes the nature of most spatial spread. It should be noted, however, that the primitives of spatial change are based on the spatial scale of observation and measurement. At some spatial and temporal resolutions, a spread process may not change at all, while at others, different forms of change may be detectable.

The temporal component of spatial spread is highly variable across all resolutions of time. Three temporal patterns signify spread processes. The first, ongoing, captures an event that begins at t0, then continues into the future, with no discernable stopping time. An example of this type of phenomenon is the movement of water in a river. The second form, temporary, is the most common form of spread modeled. In temporary spread, an object spreads at some period of time, to stop and either not exist any more, or to not change any more. An example of temporary growth is the spread of a wildfire. The last form of spread, periodic, is the spread of an object at some regular or irregular interval of time. An example of a spread process having this temporal signature would be the migration of birds from their winter to summer habitats.

It is also necessary to formalize the forces at work in spatial spread. The forces affecting spread are internal or external to the spread object, or a combination of both. What is important is to attempt to observe the forces at work in the spread phenomenon and note how they can affect the spread. Examples of spatial spread phenomena and their forcings are below in Table 1.

Table 1. Examples of Forcings of Spatial Spread

Spread phenomena	Internal forcings	External forcings
Wildfire	creation of heat waves	wind, topography
Avian migration	internal behavioral and physiological needs of birds	weather, temperature
Spread of contagious disease in a community	social contact	none

Spatial spread can be envisioned as having two components: a vector and a substrate. The vector is the entity that is spreading though space and the substrate is that which the vector is moving across, over or through. Both the vector and the substrate can be mobile or stationary. This results in four different types of spread processes (Table 2), each with their own spread characteristics including data modeling preferences.

Table 2 The Context of Spatial Spread

		Substrate	
		Mobile	Stationary
Vector	Mobile	Social Network	Blob
	Stationary	Point-Source	Aspatial Network

A spatial spread process in which both the vector and the substrate are not fixed to a geographic location is called the Social Network form of spread. In this form of spread, the location of the spreading entity is constantly moving and changing. An example is in human disease transfer, where both the substrate (people) and the vector (the disease microbes, or the disease itself) move through space. The disease must persist, and does so by using the links of the human social network.

When the substrate can move and the vector remains stationary, the spread can be classified as the Point-Source form. The substrate's mobility is a function of the geographic entities' motile nature. The stationary component of the vector refers to a constantly infecting source, or a one-time source release. This form of spread contains contamination and point-source pollution processes, where a single locus of infection changes a moving substrate, be it a river or contaminated organisms. An example of the Point-Source form of spatial spread is the range of contaminated animals after a nuclear accident.

When the substrate is stationary and the vector can move, the spread process can be defined as the Blob form. A Blob spreading entails a geographic entity moving over a landscape or other substrate and can include growth, contraction, as well as noncontiguous growth. Some examples of the Blob form of spatial spread include water flooding in a valley, dynamic animal habitat suitability mapping, or migration patterns of groups of organisms.

The final form of spread exists when neither the substrate nor the vector move through space. While it may seem impossible that something can spread while its components do not move through space, the Aspatial Network represents types of spread of an ethereal rather than tangible nature. This includes the spread of ideas and concepts not necessarily rooted to a geographic location. Of course the substrate and vector exist in geographic space somewhere, but their location does not necessarily have to relate in any way to the spread process. The network component of the Aspatial Network form of spread implies that there is some substrate that the spread process moves on, yet that substrate, a network, does not actually have to exist in space. Wireless networks, as well as internet networks illustrate this form of spread, with the spread of computer viruses operating in this context.

3. Conclusions

A cornucopia of modeling techniques can and have been used to model spatial spread. In formalizing spread, it is necessary to identify which data models and which modeling methods are needed and used. The data models available are points, vectors, polygons, fields and object fields. Each data model has challenges and advantages native to each form of spatial spread. Some data models have been used for different forms of spread due to legacy issues such as available data, computation, and understanding. In terms of modeling techniques, methods as diverse as cellular automata and differential equations have been used. It is important then to build our spread models from the ground up, taking current methods into account, while envisioning the desired data and techniques that would be the ideal model. In a more general sense, we have to leave behind the idea of creating models that use available data and techniques and instead push science, via our models, to solve problems.

This work will provide examples of formalizing special spread by using case studies from different modeling domains. Challenges to modeling dynamic spatial spread with respect to computation, current and future data availability will be presented, as well as the understanding of spread versus the modeling of spread.

4. Acknowledgements

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5. References

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