# COMPARISON OF EULERIAN & LAGRANGIAN MODELS FOR REPRESENTING A LAND-USE CHANGE PROCESS

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**ABSTRACT**

Representations of spatial processes will become increasingly important as spatial data models become more sophisticated about representing time-varying phenomena and as questions about observed dynamics are raised. Two common views from fluid dynamics can frame our descriptions of process: Eulerian and Lagrangian (Lighthill 1986). The Eulerian view focuses on change, taking a location-based perspective. Geographic information system (GISystem)-based models have tended to use the Eulerian view (e.g., IDRISI, PCRASTER) to denote a change of state at a location, usually influenced by neighboring locations. While a sequence of changes in neighboring locations may portray the movement of an entity across a space, such as a fire or diffusion front, there is no explicit representation of those entities ("fronts") as entities, i.e., no structured data object representing "a front" and no explicit representation of behaviors that fronts can exhibit. The Lagrangian view offers an alternative perspective that focuses on movement and uses an object-based approach. Individual based predator-prey models offer an example of the Lagrangian view whereby the individual behaviors of predators and prey are explicitly encoded as objects that move and interact throughout a landscape.

While discussions on Eulerian and Lagrangian perspectives in geocomputational modeling exist, they remain focused on their use as data models (field/object) (Winter 1998) or models static in the temporal domain. This research complements prior work in field/object representation (Peuquet 1988; Kemp 1997a; Kemp 1997b) by extending it temporally into the domain of process models, in addition to providing a quantitative comparison of the two methods. Historically the representation of process, and therefore time, in geocomputational analysis has been difficult. Examples of such work exist (Tobler 1979; Batty 1997; Wagner 1997; Westervelt and Hopkins 1999; Benenson and Torrens 2004) and have been increasing in number. However, the process remains difficult and is far from being streamlined or adopted by a wide user base.

Residential location (i.e., the location of residential households in a landscape) provides an archetypal example of how a process may be modeled as either Eulerian or Lagrangian. City planners and policy makers are interested in the conversion of land use and land cover types for conservation of biodiversity (O'Neill 1997), and environmental amenities and aesthetic quality (Irwin 2002). Similarly those planners and decision makers may also be interested in the movement and distribution of individuals, goods and services within a given region (Ewing 1997; Gordon and Richardson 1997). While both of the above goals are interrelated, implementation of the residential location process is substantially different depending on whether the modeler chooses the Eulerian or Lagrangian perspective.

Two residential location simulation models, corresponding to the Eulerian and Lagrangian perspectives, have been developed within ArcGIS for comparative analysis. In the Eulerian view the system is modeled as cells that become developed at each time step based on their location relative to the city center, their aesthetic quality, and whether or not the neighboring cells are developed. In the Lagrangian view, household objects evaluate the aesthetic quality, distance to service center, and neighborhood density of an available location and settles at the best location from a set of randomly selected locations. In both cases, locations of initial residents influence subsequent resident decisions. Regardless of the differences in the modeling process and the model structures, the model outcomes are similar in many regards. The differences are more important in terms of validating and communicating the value of the model more than in assessing the actual accuracy of the model.

The implications of choosing the Eulerian or Lagrangian view is evaluated by modeling the same system (i.e., residential development around a city) using both approaches and comparing the resulting: (a) modeling process, (b) models, and (c) model behavior and results. To analyze the modeling process we graphically charted the conceptual linkages between the target system and the model, and between the model output and the target system. The structures of the models are described and compared in terms of the numbers of parameters, the available opportunities for process validation, and the specific forms of process representation. Model behavior and simulation results were compared using several metrics that included general clustering descriptive statistics, landscape metrics (such as perimeter/area ratio and others), the variance and number of settlements beyond a predefined circular boundary that represents the quantity of sprawl in the system. As a benchmark, we compared both model results with two null models, similar to those in Costanza (1989). The first null model uses the initial conditions and assumes persistence of initial land uses (none) or no development. The second null model uses the same proportion of land use types and distributes them randomly.

While it is possible to model the same dynamics using either the Eulerian or Lagrangian perspectives, the choice of approach will generally result in focusing attention on different aspects of the phenomena being modeled. Some processes and dynamics are easier to represent and understand in one perspective versus the other. Similarly, one approach may be more conducive to specific types of scenario development for process management or policy creation. The results of this analysis indicate that the Lagrangian perspective produces a more realistic model structure and model output than the Eulerian perspective. Ultimately our comparison of the Eulerian and Lagrangian perspectives provides a formalization and replication of the processes understood to be governing the phenomena of interest. Similar analyses in multiple different types of systems would fortify this understanding, and significantly different results can bring attention to critical functions that dominate model behavior and simulation results.

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