ENCYCLOPEDIA OF GEOGRAPHIC INFORMATION SCIENCE

SAGE reference

Spatial Interaction

Spatial interaction is the representation and simulation of flows of activity between locations in geographical space. Locations are usually represented as discrete points in space, which in many applications might approximate an area. The flows range from physical flows of materials, such as freight; flows of people, such as traffic or migration; flows of ethereal activity, such as e-mails, telephone calls, and visits to Web sites; as well as more abstract linkages that occur in space, such as patterns of marriage and friendship, which are the activities associated with social networks.

The focus of these representations is on models that simulate **interactions** in which the time over which such **interaction** takes place is significant. There is a key distinction between routine and occasional **interaction**. Traffic in a city represents the most routine of these kinds of activity, occurring at any time of the day or night. Contrast this to infrequent flows, such as migration between regions or house moves within a city. However, in general, the representation of flows does not vary much according to type, with both traffic and migration flows being represented and simulated by similar models. **Spatial interaction** does not usually include any analysis of the underlying physical networks on which **interaction** takes place. This is studied separately under geographical applications of graph theory and network science.

Newton's laws of motion provide the analogical basis for most **spatial interaction** modeling in geographic systems. After classical physics became established in the late 17th century, scientists and philosophers argued that the forces that occurred in the social world could be modeled in the same way as in the physical world. A number of early attempts at such generalizations were made, but the most explicit application was made by Ravenstein in 1888. As part of a Royal Commission on Population in Britain, he argued that migration flows from different regions could be represented using the gravitational model that lies at the basis of Newton's second law of motion.

During the first half of the 20th century, gravitational hypotheses for various problems of movement and **interaction** in human systems became popular. Significant among these was Reilly's adaptation of the gravity model to enable hinterland boundaries to be drawn between different shopping centers, based on the points where shopping flows to competing centers were equal. However, the main force for development came in the 1950s, when these kinds of models began to be widely used to simulate traffic movements. By the 1960s, the four-stage transport model had been fashioned, in which the key stage of traffic distribution was based on the gravity model of **spatial interaction**. This was then used as the basis for various urban models linking land use to transport. Several different theoretical approaches were developed based on analogies with statistical physics and thermodynamics involving the concept of entropy and its economic equivalent utility, while a new class of discrete choice models was also introduced consistent with gravitational hypothesis but also linked to consumer choices and preferences. These **spatial interaction** models are now used routinely in traffic forecasting and planning as well as site location in the commercial sector, where they are linked to travel activity analysis in which many stage **interactions** and time travel budgets are considered.

Gravity, Potential, and Social Physics

The most widely developed model of **spatial interaction** is based on the *gravity model*, which proposes that the amount of **interaction** between any two locations, called the *origin* and the *destination*, respectively, is proportional to the product of the mass of the origin and the mass of the destination and inversely proportional to some measure of the separation. This is in analogy to Newton's second law of motion, which calculates the force between two bodies as the product of their masses divided by the square of the distance between them. This has led to the suggestion that in social systems, the separation between an origin and destination in the gravity model should be the distance raised to the power of two, which reflects Newton's inverse-square law. However, in applications to social systems, the exponent of this separation—*deterrence*, as it is called—is usually taken to be a freely varying parameter, perhaps the distance or travel time or travel cost between the origin and the destination, which is calibrated when the model is applied to some real situation.

Related to gravitation is *potential*, which can be defined as the integral of the force with respect to the space over which it acts. In terms of the gravity model, this is the total of **interaction** that emanates from an origin or enters a destination, and it is calculated by summing the **interactions** calculated between one origin and all destinations or between one destination and all origins. In this sense, potential is a measure of the overall flow into or out of a destination. If the masses of the origins and destinations are defined by the same variable, typically population, then the origin potential is equivalent to the destination population, and in this context, potential is usually referred to as *population potential*, first defined as a measure of nearness or accessibility by Stewart and Warntz in the 1950s.

Although **spatial interaction** models predict flows or movements, the key to enabling them to predict activities at different locations—origins and destinations— is through the concept of potential. Literally, *potential* means *potential energy*, which is the summation of all forces around a location, and if flows add up to activity at a location, which they usually do, then computing potential is a prediction of such activity. In this sense, it may not be the actual activity at the location, but the potential activity, and if the system is in balance, in equilibrium, it might be argued that actual is equal to potential. There is an implicit assumption that this is, indeed, the case.

Finally, there are many variants of **spatial interaction** models in terms of their mathematical and formal structures. Two that are significant involve replacing the **interaction** term with some measure of "opportunities" that compete with the actual **interaction** involved. Initially, the idea of intervening opportunities came to replace distance or travel time. Thus, as an **interaction** occurs over greater and greater distances, more and more opportunities are passed, and thus it is less and less likely that the **interaction** in question continues. If intervening opportunities are the same as distance, then the two forms are equivalent, but this is rarely the case. More recently, in the 1980s, Fotheringham extended this concept to competing opportunities within the standard **spatial interaction** framework.

Integrated Theories of Spatial Interaction: Entropy and Utility

Great progress was made with **spatial interaction** models from the 1960s to the 1980s, when they were embedded within wider theoretical frameworks and shown to be consistent with various optimization processes in physics and economics. First came the development of *entropy-maximizing methods*, in which **spatial interaction** is predicted by maximizing the uncertainty or entropy of the system subject to key constraints on their form, which were needed to ground them in space. This framework was popularized and heavily exploited by Wilson, who argued that entropy was related to the total number of possible **spatial** configurations of an **interaction** pattern. By selecting the most likely of these to occur at a macroscale level, by maximizing entropy, the resulting model was one that was the most likely to emerge under many different configurations of individual **interactions** at the microscale.

Various forms of **spatial interaction** model can be derived when entropy is maximized subject to a constraint on the total energy or total distance traveled. In short, if one maximizes entropy subject to some constraint on how much **interaction** can take place, then a generic form of **spatial interaction** models results, with the impedance or deterrence function specified as a negative exponential function of distance (or travel cost or travel time). The mass terms, the attractors, can be similarly derived, while different forms of deterrence function emerge when the different forms of constraint on total **interaction** distance or cost or time are specified. What is powerful about this framework, however, is that it enables consistent models to be derived when the set of constraints on **interaction** are varied systematically. Wilson thus derived a family of **spatial interaction** models in which constraints only on total **interaction** distance generate the unconstrained model, constraints on either origins or destinations generate the locational or singly constrained models, and constraints on both origins and destinations generate the doubly constrained model. The latter model is the one most widely used in trip distribution as part of the four-stage transport modeling process, whereas the first one is referred to as the *geographers' gravity model*, as it was formulated before the entropy-maximizing framework was developed.

In contrast to entropy maximizing, economists working in a **spatial** framework came to derive this class of model by formulating a utility function akin to entropy and set about maximizing this subject to similar constraints on **interaction** and location. After various early attempts in the 1960s, this idea was embedded within the emerging theory of discrete choice. Thus, utility in economics was extended to embrace uncertainty in choice as reflected in consumer preferences, linking the theory to more fundamental ideas in choice theory and the basic theory of consumer demand. In essence, consumers, in this case travelers, choose trips with respect to different alternative decisions, which reflect different benefit-cost trade-offs that might be realized by traveling to different locations. In essence, the models that emerged were quite similar in form to the traditional gravity models, except that methods for their calibration using the various econometric theories developed for testing consumer demand functions could be employed. Much greater scrutiny of model structures and estimates could then be developed. Daniel McFadden formulated the basic theory, for which he received the Nobel Prize in Economics in 2000, these ideas becoming a cornerstone in modern economic theory.

Spatial interaction models have become key components in more general urban models, and the cutting edge of research tends to be in either new generations of comprehensive land use model or in the transportation modeling process. In the 1960s, the most widely developed urban development model used **spatial interaction** as the basis of its subcomponents, and as these cross-sectional static models were gradually replaced with dynamic equivalents and the focus moved from aggregate to disaggregate, **spatial interaction** models were adapted accordingly. The current wave of land use transport models fuses **spatial interaction** concepts usually articulated in terms of utility maximizing or discrete choice models with highly disaggregate behavioral processes in which individuals and agents represent the system being simulated. In transportation modeling, **spatial interaction** is now complemented with travel activity analysis. Large-scale urban models are now being constructed as agent-based structures in which individual travel behavior is much more explicit in terms of choice. In fact, **spatial interaction** patterns consistent with the tradition of aggregate models emerge from the predictions of this new generation of models, such as TRANSIMS and URBANSIM, and it is within this domain that new forms of **spatial interaction** model are being created.

—Michael Batty

Further Readings

Batty, M. (1976). *Urban modelling: Algorithms, calibrations, predictions.* Cambridge, UK: Cambridge University Press.

Ben Akiva, M. , & Lerman, S. (1985). *Discrete choice analysis: Theory and application to travel demand.* Cambridge: MIT Press.

Carrothers, G. A. P. *A historical review of gravity and potential concepts of human* **interaction***. Journal of the American Institute of Planners* vol. 22 (1956). pp. 94–102

Mirowski, P. (1989). *More heat than light: Economics and social physics, physics as nature's economics* Cambridge, UK: Cambridge University Press.

Oppenheim, N. (1995). *Urban travel demand modeling.* New York: Wiley.

Waddell, P. *UrbanSim: Modeling urban development for land use, transportation and environmental planning. Journal of the American Planning Association* vol. 68 (2002). pp. 297–314

Wilson, A. G. (1970). *Entropy in urban and regional modelling.* London: Pion Press.

Entry Citation:
Batty, Michael. "Spatial Interaction." *Encyclopedia of Geographic Information Science.* Ed. . Thousand Oaks, CA: SAGE, 2007. 417-19. *SAGE Reference Online*. Web. 20 Jan. 2012.