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CONCEPTUALIZING SPACE AND TIME: A CLASSIFICATION OF GEOGRAPHIC MOVEMENT

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CONCEPTUALIZING SPACE AND TIME: A CLASSIFICATION OF GEOGRAPHIC MOVEMENT

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ABSTRACT

CONCEPTUALIZING SPACE AND TIME: A CLASSIFICATION OF GEOGRAPHIC MOVEMENT

By

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Movement, in a spatial and temporal context, is a significant and unifying theme in geographical understanding. Geographic movement, or spatial change of a phenomenon, is associated with virtually all geographic description, explanation, and analysis at some scale. Because geographic description details the spatial component of a phenomenon, and since most geographic explanation strives to uncover patterns and processes that are, for the most part, inherently linked with change, much discussion of geographic phenomena, in one way or another, considers movement. Conceptualizing the dynamic nature of a phenomenon as it evolves through space and time is a grounding principle that broadens our understanding of geography. In an increasingly complex and interactive world, the need to study, manage, and understand the critical interface between physical and human environments is becoming more urgent and has precipitated technological advancements in the dynamic spatiotemporal capabilities of geographic information systems (GIS) and associated visualization and representational techniques. Such efforts require a thorough knowledge of the intrinsic characteristics associated with changes in space, coupled with changes in time. A comprehensive understanding of the underlying dynamic structure associated with movement is necessary before accurate, integrative, and insightful analyses, explanations, and representations of complex, geographically dynamic phenomena can be performed.

Using the logical subdivision method of classification, geographic movement is conceptualized by its abstract spatial and temporal components creating a matrix of twelve unique classes characterizing the form of movement. Based on three temporal conditions identified as continuous, cyclical, and intermittent, in combination with the

four fundamental features of space represented by points, lines, areas, and volumes, a classification of geographic movement is presented. The organization is a simplified framework that offers a movement language with which to describe the movements associated with diverse geographic phenomena that includes all physical, social, economic, cultural, and political realms of geography. Classifying geographic movement by its changes in time and space serves as a useful construct that facilitates the comprehension of the general ideas and principles intrinsic to geographical patterns and processes and provides a solid foundation for greater explanation and understanding of the complex interactions among diverse geographic phenomena.

To my family and friends,
who have traveled this evolutionary journey with me.

To Zach and Tobes,
who spent countless hours with me on the computer.

And especially to Will,
whose enduring patience, encouragement, and understanding
I will not soon forget.

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... movement is a very significant and central element in geographical understanding... understanding movement should lead directly to a better understanding of what is happening, a necessary accompaniment to the understanding and study of what is there.

Roger Robinson
Ways to Move, The Geography of Networks and Accessibility (1976, preface)

We currently possess in geography a sound basic methodology for classification. Let us ensure... that we make an efficient use of [classifications] in pursuing a deeper understanding of the phenomena we are concerned with.

David Harvey
Explanation in Geography (1969, 348)

... it is conceivable that a synthesizer may someday, in fact, suggest a schema according to which a variety of forms of movement and phenomena can be viewed together.

John C. Lowe and S. Moryadas
The Geography of Movement (1975, 226)

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Chapter 1

MOVEMENT AND GEOGRAPHY

To understand geographic phenomena, one must often comprehend the interrelationships between various geographic elements, including space and time. Understanding the dynamic nature of these inherent structures is necessary for the description, explanation, and analysis of the interactions of geographic phenomena with earth, humans, and each other. Using the traditional positivist approach to science, phenomena from all branches of geography are generalized by abstracting the movements associated with these events, occurrences, and processes. This conceptualization is presented as a paradigmatic classification that facilitates the comparative study of all geographic movements by summarizing their similarities, differences, and relationships as they occur through space and time and across all scales. As such, the conceptual framework bridges the gap between the various scientific approaches and fields of study not only within the discipline of geography, but within other disciplines concerned with spatiotemporal structures.

Movement is an integral part of geography. Spatially dynamic geographic phenomena are those that refer to motion, the elements and connections of which constantly change spatial location (Griffith and Lea 1983). Geographic movement, or spatial change of an object, is associated with virtually any geographic description, explanation, or analysis at some scale. From transportation routing and commodity exchanges to the theories of diffusion, migration, and desertification, movement over time is an inherent feature in geographic understanding. Sometimes geographical analyses involve the direct examination of the motion itself, such as daily trip pattern studies where personal use of time and space in an urban environment are examined. With others, spatial change may not be the subject of direct inquiry, but rather may be viewed historically in the examination of a phenomenon over time, as with the case of 'moving regions.' In describing a region such as the corn belt in the United States, the boundaries of the area may be examined at a particular point in time and are considered static. At this point, several things may be analyzed such as what attributes comprise that region, how this region is similar to and different from other regions, and what effect the region has on the population and the landscape. However, an even greater understanding of the properties and influences of the region can be gained by examining the corn belt over several years. With the passage of time, the composition and boundaries of the region change, causing consideration of the dynamics of a region and leading to new insights with regards to patterns related to that area.

This inclusion of the time variable, which permits a description of change in the spatial location of the variables represented, is what separates a dynamic process from a static model (Martin, Thrift, and Bennett 1978). Geographic explanation may begin with static descriptions, but dynamic processes are eventually factored into analysis as change over time is observed, analyzed, and interpreted (Graf and Gober 1992). As Hardwick and Holtgrieve (1990, 310) note, "static views of the earth are useful for descriptive purposes, but true understanding of movement and change is necessary for analysis." Conceptualizing the dynamic nature of a phenomenon as it evolves and interacts through space and time is a crucial principle in geographical understanding.

Traditionally however, movement has not been regarded as a significant integrating concept within the geographic discipline. Rather it has been viewed or interpreted as a consequence or byproduct of something larger that is taking place. Theories of movement for the most part have been lodged under different headings, such as spatial interaction and migration theory. Focus has usually centered on the overall process of which motion is a part; that is, the 'what,' 'why,' and 'where from' and 'where to' of a subject that is moving. Movement has often been relegated to the last chapters of regional geography books, a "mere appendage" to the meat of regional description, even though it lies at the core of many geographical analyses (Robinson 1976, v). However, in recent years geographers have sought to understand the activities and movements on the earth's surface which help to explain the distributions of humans and their works (Robinson 1976).

In 1984, the Association of American Geographers and the National Council for Geographic Education developed a set of guidelines for geographic education for elementa and secondary schools across the United States. The joint committee felt that in order to improve geographic education, the very definition of what constitutes geographic knowled had to be clearly articulated (Knight 1994). In support of the interdisciplinary nature of geography, the guidelines define five central geographic themes: location, place, relationships within places (human-environment interaction), regions, and *movement* (Joir Committee on Geographic Education 1984). The framework, published in the landmark *Guidelines for Geographic Education*, is instrumental in demonstrating that geography is nc mere place names (e.g., capitals, countries, and rivers), but rather is the whole science of th significance of location. Other frameworks for school curriculum planning can be found i the geographic literature because, as Hill (1989, 4) explains, "changing perspectives are, in fact, to be expected in a dynamic discipline." However, the five fundamental themes, as defined, serve as a useful mechanism by which geography can be clearly understood. Acknowledging movement as a central theme within the geographic discipline is an important step towards greater and more comprehensive understanding of geographic phenomena.

With the technological advancements of geographic information systems (GIS), spat decision support systems, and visualization techniques, coupled with the exponential accumulation of spatiotemporal data and the expanding data handling capabilities of modern computers, the time has come when the ideas of temporal geography and complex dynamic process models developed in various fields can begin to be tested and refined in a integrated environment (Peuquet 1994). Currently, representations typically used within GIS assume a world that exists only in the present. Information contained within a spatia database may be added to or modified over time, but a sense of dynamics, or change thro time, is not typically maintained (Peuquet and Duan 1995). Enhancement of the spatiotemporal capabilities of geographic information systems is one area of research that receiving much attention. A key element in this work is how to store historic and anticipated geographic data effectively so that geographic information systems are capabl tracing and analyzing changes in an area and ultimately of allowing temporal modeling a simulation of geographic processes (Langran 1992; Peuquet and Duan 1995). Possible future scenarios of implementing spatiotemporal GIS could include the forecasting of dis spread in forest resource management, gauging urban development rates, and monitoring and evaluating long-term land use and cover changes for conservation and planning purp (Langran 1989a).

Researching dynamic geographic processes has also begun to occur with visualizatio techniques. Visualization, as an act of cognition, is the human ability to develop mental representations by manipulating, rotating, twisting, and inverting two- or three-dimensio pictorially presented visual stimuli (MacEachren 1992; DiBiase et al. 1992). This ability identify patterns and create or impose order involves recognition, retention, and recall of multidimensional structures in which change among the spatial, temporal, and attribute dimensions is depicted (Golledge, Dougherty, and Bell 1995). Visualization in science serves many purposes: exploring unfamiliar data sets, identifying meaningful patterns or anomalies in data, and communicating insight revealed by visual analyses (DiBiase et al. 1992). Visualization techniques use graphic representations such as maps, remotely sense images, graphs, sketches, diagrams, and photographs to make spatial contexts and proble visible by bringing three-dimensional objects to life in our visual imagination (MacEachr et al. 1992; Dorling 1992). The development of new and more powerful visualization to such as computer animation and three-dimensional modeling has become a major preoccupation in current scientific visualization research. Computer animation allows geographers to better understand dynamic phenomena by incorporating change in space through time with the use of movement, perspective shading, and shadows to com for the lack of an actual third spatial dimension on the flat computer screen (DiBi 1992).

Research Problem

Geographic explanation revolves around the spatial element of the phenomer investigation since space is an inherent feature in geography. Space is also naturall with time; the dimensionalities of these inherent geographic properties interact wi another as they evolve and change across the landscape. Such transformations in s through time occur across all scales and refer to the movement associated with geo phenomena. Identifying geographic movement by the spatial and temporal config leads to the heart of geographic inquiry: "much can be learned about the world by its forms and patterns, even when such observation does not contribute directly to explanation" (Goodchild 1992, 159). Whether spatial movement is a primary foc geographical explanation about a spatially dynamic phenomenon (e.g., transportat planning), or whether it is indirectly involved in an examination over time where and interactions among phenomena on the landscape are revealed, (e.g., analyzing changes), the principles are necessary components of geographical understanding.

Interpreted as a dynamic function of many geographical analyses, movement receiving increasing attention in the research community. In addition to the conti examinations of social processes such as daily activity patterns and urban growth, advancements in the understanding of the effects of human activities on the natur environment are now being explored with increasing urgency, especially in researc involving geographic information systems, visualization, and cartography. Improv these computerized tools in their spatiotemporal capabilities have aided researcher end by facilitating greater understanding of complex dynamic processes at multipl geographical scales. However, before comprehensive conceptualizations of movem

associated with these processes can be made, the individual components of motion be abstracted. Once the underlying attributes of geographic movement are more f understood, then significant progress towards performing integrative and insightfu and visualizations of complex, spatially dynamic processes can be achieved.

The key to improved understanding of geographic movement is to transcend examples and to establish the significance of some general principles and concepts sense out of seemingly different facts (i.e., diverse geographic phenomena) (Hartsh 1959). The acquisition of concepts and categorical structures is a fundamental pa learning process and leads to the development of "a new set of precepts" with whic understand and communicate about the world (Patton 1997; Hardwick and Holtg 1996, 273). Classification, the first and most important step in the development process-based model, makes it possible to trace a certain order in the study of phen and to uncover the concrete content of generic concepts of different scope (Willm Gaile 1992). As an important and useful generalization step in conceptualizing a matter, geographers have long relied on categorization to place order on an often c world. Classifying geographic movement allows the comprehension of the general principles underlying geographical patterns and processes and provides a foundati understanding the complex interactions among diverse geographic phenomena.

Using the logical subdivision method of classification (classification occurs fr general to the particulars) and adopting a morphometric analytical approach to ex (inquiries dealing with the spatial structure and form of phenomena), this disserta presents a classification scheme of geographic movement (Harvey 1969). Geograp movement involves a change of spatial locations over time. As such, both space ar identified as the important inherent properties of any and all geographic movemen arranged conceptually into a two-dimensional matrix. Spatially, geographic objec composed abstractly of points, lines, and areas, with areas sometimes extending in three-dimensional space containing volumes. These four spatial characteristics of

dynamic phenomena represent the first subdivision of the classification. The secon inherent property of geographic movement is time, which has associated fundamen features such as duration and periodicity of phenomena. A movement is classified occurring nonstop, occurring repeatedly in a regular fashion, or occurring infreque no definitive temporal pattern. Based on these three temporal conditions identifie continuous, cyclical, and intermittent, respectively, in conjunction with the four sp features of movement represented by points, lines, areas, and volumes, geographic movement is organized into twelve unique classes. Each class is described in terms abstract spatial and temporal components and, with attention given to widely rang of interpretation, geographic phenomena exemplifying each movement category ar discussed.

The premise of this classification is that any spatially dynamic geographic ph can be conceptualized by its patterns and processes of movement through space an and can be characterized by at least one of the twelve movement classes. The prese classification serves as a useful and integrative framework for modeling, interpretin analyzing, associating, and explaining dimensionally complex, if not distinct, patte arrangements, and locales that are created on the landscape when human and phys phenomena interact amongst each other. By abstracting spatially dynamic geograp phenomena into their natural structures of motion, the inherent spatiotemporal dimensionalities are discovered, thereby leading to a more complete interpretation cognition of the interplay of space and time not only with one another, but with o fundamental principles important in the explanation of phenomena such as spatial interaction. Understanding these complexities will facilitate a greater understandi diverse and integrated dynamism of the geographical factors that create regional m the earth's surface.

Chapter 2

CLASSIFICATION IN SCIENCE AND GEOGRAPHY

> "... we would never have learned anything if we had never thought how objects resemble each other, and whether they manifest the same properties. If every object in the world were taken as distinct and unique, our perception of the world would disintegrate into complete meaninglessness. The purpose of classification is to give order to the things we experience. We classify things so that we may learn more about them."
>
> (Berry 1972, 1)

As the simplest form of analysis, classification is the act of placing events, object or observations into categories based upon their similarity with each other. Classificati are constructed as a means for better understanding the world in which we live. Classification plays a necessary and crucial role in scientific explanation; the function c positivist science is to develop generalizations and conceptual frameworks about realit and the classification of phenomena is often the first step taken towards scientific explanation in the diverse branches of science, including geography. Every classificatio should have a useful purpose, the most important being that inductive generalizations ca be made about the objects under study. The classification method used, the number an representative archetype of categories to be constructed, and the identification of possi relationships among categories requires decisions that will reflect the analyst's view of world. As knowledge about the objects to be classified becomes more complete, the classification should be modified to reflect newly acquired information. The determination of class structures is based on prior understanding and theoretical concep held by the classifier. Although typology building should follow certain principles in logic, the development of a classification scheme is largely subjective. A classificatio may be deemed adequate if it serves its purpose well. The following sections will

examine each of these important features of classification in more detail beginning wi
what is classification and why is it an important part of explanation in science.

Classification Defined

Classification consists of the grouping of events, objects, or observations (hereaft referred to collectively as *objects*) into a class or group because of certain attributes or relationships they have in common. Classification is a logical operation in which a ge concept is divided into classes based on the criterion of similarity of the objects ente into a class and on their differences from objects entering into other classes. Berry (19 300) defines this principle of classification as "the similarity of members of the class the differentiation of members from nonmembers." Matching and categorizing objec exhibiting similar characteristics is the process by which types or 'typologies' are produced (Johnston 1970). As a "filter" for ordering data (Harvey 1969, 327), classification can be built on various principles: morphologic, genetic, temporal, spa qualitative, etc. However, all must follow certain general and unalterable laws of log (Armand 1965).

As a type of 'cognitive description' that asks "how may the phenomena being stu be ordered and grouped?" (Harvey 1969, 82), classifications may range from simple primary observations through to sophisticated descriptive statements. At one end of t scale, the act of classification may involve the simple giving of a name to a group of objects, whereby all objects are automatically classified into two classes, those posses the attributes connoted by the name and those not possessing them (e.g., houses and no houses). At the other end of the scale, the term classification may be used to describe conscious act of devising a formal scheme for the grouping of a definite set of objects an elaborate hierarchy of classes (e.g., land use classification) (Gilmour and Walters 1 Regardless of the level at which considered, classification is an important operation i empirical positivist science.

The Role of Classification in Scientific Explanation

Classification is the first step the scientist takes on his or her route to expl (Harvey 1969; Abler, Adams, and Gould 1971). Classification is an organizat process where classes are grouped according to *constructs*, which are ideas about experiences that are products of, and answers to, our semantic questions (e.g., a flower or plant) (Abler, Adams, and Gould 1971). As the foundation of positi science, classification defines the *concepts* to be studied (Johnston 1986). The fi scientific concepts is to mark the categories which will tell us more about a sub than any other categorical sets (Kaplan 1964). A concept is scientifically valid identifies properties which are causes of many other properties. This process o formal conceptual structures in science is referred to as *theory.* Theories are stru composed of laws and the rules by which those laws are put together. As Kaplar 53-54) explains, the formation of concepts and theories in science go hand in ha knowledge of a particular subject matter grows, our conception of that subject changes; as our concepts become more fitting, we learn more and more... the be concepts, the better the theory we can formulate with them, and in turn, the bett concepts available for the next, improved theory."

Theory building is operational at every level of the process of scientific e The objective of science is to devise theories or laws that explain patterns and b the natural and social worlds (Goodchild 1992). A theorist is someone who ob portion of the world and seeks to "find order in the booming, bustling confusio realm of experience" (Dubin 1969, 5). The idea of order, and the tools utilize the sense of order, are in the mind of the theorist. Classifiers, as theorists, take information generated by empiricists and chroniclers and order it within the p framework (Johnston 1991). The classifier begins to ask questions about the co which he or she has put in the foreground of attention and thus begins to sort par experience into classes of objects. In doing so, the significant criteria to be use

classifying objects are defined and the process may also involve arranging the cri some order of importance. This implies some *a priori* notions about structures, s what properties or attributes are important for differentiating objects in a given s This notion that the proper concepts are needed to formulate a good theory, but t good theory is needed to arrive at the proper concepts is known as the *paradox of conceptualization* (Kaplan 1964). Hence, a strong link binds classification and th type of theory which will emerge is partly conditional upon the nature of the que asked and on the nature of the explanatory framework chosen. Although these de typically made subjectively on the basis of preconceived ideas (Johnston 1986), classifications are constructed based on the abstraction and generalization of the around us.

This abstraction and generalization of the relationships among facts, which one to see patterns that are much more difficult to discover from the data thems perhaps the most important purpose of classification systems; that is to say it pe *inductive generalizations* about the objectives we want to study and understand (A Adams, and Gould 1971). Induction is the presentation of information about th a way that suggests explanation (Goodchild 1992). Generalization is the orderin observations and experiences and as Gilmour and Walters (1964, 3) claim, is the method by which humans cope with the "otherwise chaotic multiplicity of indivi objects" in the world around them. Others have expressed similar views on the e humans to deal with their surroundings: Chorley (1968, 42) refers to classificatio accumulation of a backlog of information which is then dissected and categorize convenient manner;" Harvey (1969, 348) sees classification as a means to an end: grouping sense-perception data into classes or 'sets' we transform a mass of unwi information so that it may be more easily comprehended and more easily mani Abler, Adams, and Gould (1971, 150) call classification "a form of intellectual shorthand" which makes the "transmission of knowledge easier."

In essence, creating classifications is a way in which we summarize data and
into a form with which we can comprehend. Not only do typologies necessarily
propositions but, by isolating crucial distinctions between diverse phenomena, a g
typology will facilitate the creation of further propositions (Clark 1972). Grigg
470) uses regionalization to explain this point: "many generalizations in geograpl
from the comparison of two different regional systems; thus, for example, if in an
country an areal classification on the basis of soil type is compared with a classifi
according to land use, then a number of generalizations about the relationship betw
two may be inferred." If similar parts of the earth's surface are grouped together,
statements can be made about the areal classifications which are applicable to all
parts of the classification. Classifications are not fruitful ends in themselves, but
enable the ordering of unorganized data or facts, thus producing valuable insights
relationships between classified phenomena (Clark 1972; Abler, Adams, and Gou
1971).

Thus, classification occupies a key position in the development of every scie
scholarly discipline can function without a systematic approach to the objects und
(Armand 1965). Some scientists have argued that the state of classification in a s
a measure of its level of development (Abler, Adams, and Gould 1971). In the e
stages of a discipline's development, theoretical assumptions may be vague and il
defined. In the later stages, classification procedures tend to become part of exp
design where measurement and classification of data may be derived directly fro
(Harvey 1969). Significant classifications have dominated such disciplines as ch
geology, zoology, and entomology; the hierarchical system of biological taxonon
perhaps the best known scientific classification (Goodchild 1992). The most volu
literature devoted to classification has been by or for librarians. While such works
dealt with the organization of printed matter, it can be said that classifications in
librarianship represent extensions of knowledge as a whole (Gilmour and Walters

In geography, classifications are widely used in all branches of the discipline (Armand 1965). Virtually all phenomena geographers deal with have, at some time or other, been classified such as land uses, towns, climates, soils, coast lines, rivers, economics, and above all, regions (Harvey 1969).

Evaluating a Classification

Broadly speaking, the preference for one classification, as a theoretical model, over another is a matter of *consensus.* What is meant by consensus is that a group of people sharing an interest in some set of observations (i.e., 'experts') come to agree that one theoretical model *best provides understanding* or permits accurate predictions about the observational set. For such agreement to exist there must be some common agreement on the boundary containing the observations, that the framework of logic employed in building the theory be shared by all experts, and that a "proof" of a theory is performed through empirical and/or statistical tests (Dubin 1969, 13). Whenever people agree among themselves that understanding has been more or less satisfactorily achieved or that predictions have proved accurate within agreed-to units of error, then the theoretical models will continue to be favored. Thus, the continuing viability of a theory rests on human consensus (Dubin 1969).

The argument about the adequacy of a theoretical model is often an argument about the logic employed in constructing it (Dubin 1969). A theoretical model starts with things or variables (i.e., units) whose interactions constitute the subject matter of attention. The model then specifies the manner in which these units interact with each other (i.e., laws of interaction). Since theoretical models are usually of limited portions of the world, the limits (i.e., boundaries) must be set forth within which the theory is expected to hold. Most theoretical models are presumed to represent a complex position of the real world, part of whose complexity is revealed by the fact that there are various *system states* in each of which the units interact differently with each other. Once these four basic features of a theoretical model are set forth, the theorist is in a position to derive conclusions that represent logical and true deductions about the model in operation, or the *propositions* the model.

In classification, scientific laws are presented as *functional laws*, which are statem of the interrelationships among two or more classes of phenomena. However, prior to creation of such statements, it is necessary to define the properties or *membership laws* allocating phenomena to their relevant classes. The determination of the relevant properties is essentially a subjective issue, and no general rules can therefore be applie except to say that the most important properties should be given the greatest weight. objective guides exist to which an investigator can refer for assistance in classifying. Drawing up membership laws is not a straightforward task; much debate may take pla (e.g., when does drizzle become rain or youth become adulthood?). Unless the indivi form definite groups, there are likely to be minor alterations in the classification (John 1986). Errors in drawing up the membership laws can lead to failures in the search for functional laws, because the classes are not internally homogeneous. The membership must then be reconsidered in order to allow scientific progress.

Classifications are not absolute and as such, they must be modified as more knowledge is gained about the objects under study. As theory develops, new relations emerge, making it possible to classify what previously seemed to be very disparate ev and objects into some unified system (Harvey 1969). The belief, however, that there i one unified system or true classification of a subject matter has had "unfortunate consequences" (Grigg 1965, 471). According to Gilmour and Walters (1964, 20), wh clearly emerges from the literature on library classification is how naive the nineteent century materialists were. Interested in objectively determining facts as a basis for th classification, these taxonomists accepted the idealistic view that a single, true, natur classification "must exist and awaits discovery." The authors suggest that this quest to discover a unique and accurate classification is too optimistic and is a widely and str held "delusion" of many scientists, particularly biologists. Abler, Adams, and Gould (1971, 158) believe geographers are no exception: "in the development of geographic thought, the whole idea of the natural region... has had a debilitating stranglehold on r geographers' thinking." Johnston (1986, 471) agrees that geographers, in their attemp establish regions, often perpetuate the misconception that a single classification exists nature: "even among those who recognize that regional systems are not a classification entities that exist in nature there is still a tendency to forget that lines on a map are ra real and that any given classification or regional system is but one way of looking at t world." Well-established regional systems tend to become, in the mind of some reac the reality rather than simply a device for representing sections of reality and this, Johnston (1986, 471) says is unfortunate: "if regions were real entities then there could correct regional system."

Modern logicians and classifiers would agree that there can be no natural classification in the sense that there is one and only one classification which will serve purposes (Grigg 1965). The idea of a single, true classification suiting a subject matt does not consider the subjective nature of classificatory procedures. Classifications a constructed for a particular reason; there can be as many schemes as there are inquiries about a subject. To some, classification is a means of data exploration, either to determine convenient ways of summarizing information, to find new and potentially useful hypotheses, or to produce a universally true typology. To others classification provides a means of facilitating hypothesis-testing or model-fitting, while still other concerned with developing improved modes of production (Berry 1972). Harvey (19 326) suggests that since different classes are required for different purposes, "we poss therefore, no means of assessing the adequacy or efficiency of a given classification independently of the job it is designed to do."

How well a classification fulfills a particular inquiry is largely dependent upon purpose for which it was created. To ask whether one classification is "better" than an

without considering "better for what purpose?" is an unanswerable question; the util given system of classification cannot be answered independently of its purpose (Gil and Walters 1964, 3). No method has been devised by which it is possible to com classifications and decide which is the best (Johnston 1968); instead, a classificatio be judged as "good" if it has an aim beyond the classification alone (Abler, Adams Gould 1971, 151). There can be no use in placing an object in a scheme unless som more than the fact of being in the classification is implied. Grigg (1965, 471-472 that for some classifiers such as geographers, classification becomes no more than a of identification; once the object has been satisfactorily classed, it is forgotten: "m regional systems seem to be devised as an end in themselves... the definition of a re regions becomes important in itself rather than as a means to understanding the area question." A classification can thus only be understood not as an end in itself, but a background of purposes for which it has been made (Gilmour and Walters 1964).

Classification Purposes

Classifications should be designed for a distinct purpose; they rarely serve tw different purposes equally well (Grigg 1965). The many purposes of classification however, be grouped into two fundamental types: *natural* and *artificial*. Gilmour a Walters (1964) have suggested that the most useful and informative way of distingu between purposes for classifications and appreciating how classifications deal with objects around us is to use the terms 'general-purpose for natural classifications and 'special-purpose' for artificial classifications. Grigg (1965) agrees with the usage c terms because of the confusion that has resulted in the interpretation of the distincti between natural and artificial classifications. Natural classifications assign objects classes whereby the variation among individuals within each class is minimized anc variation between each group and members of other groups is maximized (Abler, and Gould 1971). A classification may be considered natural if the attributes chos

the basis of classification are significantly related to the attributes conceptualized elsewhere in our thinking (Kaplan 1964). The possibility of making a natural classification of a set of objects depends on the existence of a powerful influence opera on them which causes a number of attributes to "hang together" and be highly correlate their occurrence (Gilmour and Walters 1964, 4). If there is one influence more powerf than any other, then there will be one classification that is more 'natural' than any other, whereas if several influences are equally powerful, there will be several more or less equally natural structures. Using an example of furniture classification, Gilmour and Walters (1964, 4) demonstrate this point: "the influence of intended use is paramount, a classification into chairs (sitting on), tables (for placing things on), etc., is a more nat one than any other (e.g., date or place of manufacturer)."

A natural classification may be designed to serve many purposes, but it is unlikel serve all purposes with any but a low level of efficiency (Harvey 1969). As a rule, gene purpose classifications are developed to give names to things as members of groups an transmit information, but they may not offer any explanations about the objects classif (Grigg 1965). Most modern views tend to regard general purpose classifications as performing the function of data-storage systems, thereby providing a "comprehensive nomenclature" for working on empirical problems (Harvey 1969, 331).

Artificial or special purpose classifications serve as the first formal step in scienc (Abler, Adams, and Gould 1971) and may be developed to test or deal with specific hypotheses or problems. The problems themselves define the criteria and method to b used in such cases (Harvey 1969). Artificial classifications are developed for a special purpose and we cannot do more with it than was first intended (Kaplan 1964).

The thematic disciplines, such as economics and psychology in the social sciences physics and chemistry in the natural sciences, use a general focus upon comparatively narrow classes of phenomena. In contrast, the integrative disciplines such as history an geology generally address broad classes of phenomena, including those that fall under specialized focus of the thematic disciplines (Casetti 1993). However, some discip such as geography, have moved to bridge the gap between the general and the specific methodologies and conceptual frameworks pertaining to scientific explanation. In particular, classifications of regional systems by geographers have been both general specific; types of places, regardless of proximity to one another, are classified accor to a certain set of attributes, such as climate, language, cultural heritage, human use o earth, etc. Specific regional systems differ from general regional systems in that all parts of a homogeneous region must be spatially contiguous; regions are defined not by combinations of intrinsic attributes, but by location as well (Abler, Adams, and 1971).

Regardless of whether a classification is considered general, specific, or perhap culmination of the two, it is the purpose itself that drives the classification process. primary goal of classification must be thought out explicitly before attempting its construction (Grigg 1965; Rees 1972). Once a purpose for a classification has been defined, the classifier, on the basis of preconceived ideas, must then make subjective decisions concerning the choice of classification technique and the definition of a gro Particular care must be exercised in the choice of relevant properties on which to cla before proceeding with analyses.

Procedures for Classifying

Classification can be reached by two distinct approaches, *logical subdivision* and *agglomeration* (Grigg 1965). Logical subdivision divides a population, using a series steps, into groups according to stated criteria, often the presence or absence of two o attributes. Agglomeration takes a number of individuals and, by one of a large num techniques based on discriminatory analysis, assembles them into classes according some grouping or clustering procedure. Grouping similar observations is simply the side of the coin from subdividing a population; only the perspective at the starting p different (Abler, Adams, and Gould 1971). With the agglomerative approach to classification, individuals are grouped together on the basis of some observable and measurable properties. No assumptions are made, or need to be made, about the cause of the differences and similarities between the individuals grouped in the same class. But in subdivision the genus is divided on some principle and thus, a logical subdivision presupposes that there is some understanding of the system being constructed (Grigg 1965). Using this distinction, Harvey (1969, 334) suggests that given a purpose, and given adequate information regarding the criteria to be used in classifying, objects can be assigned using two fundamentally different kinds of classification procedures: "classification from above" which refers to logical subdivision and is considered to be deductive classification, and "classification from below," which refers to agglomeration or inductive classification.

Logical Subdivision

Sometimes referred to as as the 'definitional' method of classification, logical subdivision involves a conscious laying down of certain attributes that an object must possess in order to belong to a schema and is a good method to use when avoiding misunderstandings is important (Gilmour and Walters 1964). The divisive approach to classification treats the whole population as a single type and then divides it into subdivisions on the basis of some principle (Johnston 1970). The initial class to be divided is called the *genus*, which is divided into its *constituent species*, and each species can be further subdivided on the same principle, sometimes referred to as the *fundamentis divisionis*. For example, the universe of land parcels can be subdivided based on the principle of its land use (Figure 2.1, *a*). The first order of subdivision yields six major categories of land use: building lots, farm land, forest, public utilities, recreation, and waste (Figure 2.1, *b*). Each of these major land use categories can be further subdivided yielding second order subdivisions such as farm land into pasture, cultivated land, and

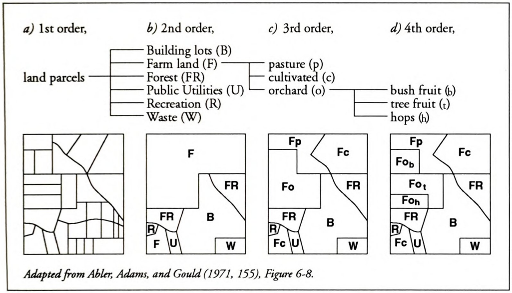


Figure 2.1 An Example of the Logical Subdivision Method of Classification.

orchards (Figure 2.1, *c*). Continuing with the hierarchical subdivision, third order land use classes of orchard farmland yield bush fruit, tree fruit, or hops (Figure 2.1, *d*). As this land use example demonstrates, the logical subdivision of a classification should proceed at every stage, and as far as possible throughout the division, upon one principle (Grigg 1965). The first and most important rule in logical subdivision is that a division must be exhaustive; the purpose of logical subdivision is to distinguish all the species within a genus.

Techniques used in logical subdivision include the creation of Venn diagrams and stepwise disaggregation into a hierarchy of classes (Abler, Adams, and Gould 1971), the latter based on the notion that different criteria may be adopted at different levels of the process (Rees 1972). One particular form of hierarchical subdivision is ***dichotomous division***, the purpose of which is to isolate a single species by dividing upon the principles that a class must either possess a given characteristics or not possess it. For example, all the members of a university can be divided into teachers and non-teachers. Teachers can be subdivided into professors and non-professors, professors can be classified further as tenured or non-tenured professors. Non-tenured professors are identified as either assistant

or non-assistant, non-assistant professors are categorized as lecturers or non-lecturers, and so forth (Grigg 1965).

With logical subdivision, the division of the universal set takes place in a series of steps, and at each step one property or set of properties is used to differentiate between classes. The kind of classification which emerges, however, is very much affected by the criterion selected at each step and the order in which the criteria are employed. In developing classifications by this route, criteria need to be placed in order of significance. This assumes that much is known about the phenomena being classified; the classifier uses an adequate theory about structures to deductively identify classes. Logical division is best suited as a method for classifying when the classification is viewed as the culmination of scientific theory.

Agglomeration

Agglomeration, the most popular approach to classification by far among geographers, begins by treating each object as a separate unit and proceeds to group similar units into types (Johnston 1970). Combining individual observations on the basis of observable and/or measurable similarities forms a smaller number of clusters (Grigg 1965). Census geography is a good example of how detail is lost in order to gain ease in interpretation each time observations are grouped into classes (Abler, Adams, and Gould 1971). Census geography is a collective term referring to the geographic entities used by the Census Bureau in its decennial collection and tabulation operations. Census Statistical Area Committees (CSACs), in cooperation with the Census Bureau, identify such statistical entities. The grouping is designed to create relatively homogeneous units with respect to population characteristics, economic status, and living conditions at the time the CSAC established them (US Census Bureau 1997). Households can be described according to socioeconomic attributes like income, educational level, and age of housing unit. Blocks, the smallest geographic entity for which the Census Bureau reports decennial census information, are formed by grouping homogeneous, spatially-contiguous households (Figure 2.2, *a, b*). Each block is assigned a unique three digit number with similarly

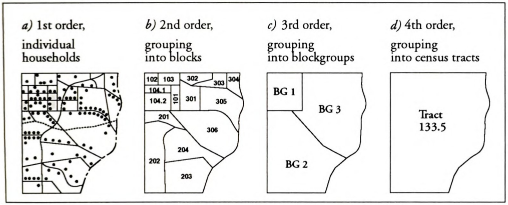


Figure 2.2 An Example of the Agglomerative Method of Classification.

homogeneous adjacent blocks given the same first digit in its census reference number. From these, combinations of similar blocks called blockgroups are created (Figure 2.2, *c*), from which census tracts (or block numbering areas) are formed (Figure 2.2, *d*). The grouping procedure for each of these levels uses the same principles of spatial contiguity and socioeconomic homogeneity, with each higher order grouping employing more broadly defined criteria.

The agglomerative method of classification by which individuals are compared may use dichotomous attributes such as male versus female; alternatively, observations may be measured in terms of gradient variables such as income or height. In using continuous variables, the limits of each class must be defined before grouping of observations can begin (Abler, Adams, and Gould 1971). Multivariate measures utilizing continuous data may also be employed in qualitative approaches for comparing individuals, which may also use either the presence or absence of certain attributes of phenomena (Johnston 1968). In situations where a good deal of uncertainty presides, groupings will likely yield much more realistic classifications. Hence, grouping is often regarded as an inductive procedure by which the phenomena being examined are searched for regularities and for significant interrelationships. As such, grouping is appropriate to use in situations in which the significant properties are not known.

A type of agglomerative classification uses the *typological method*, which Gilmour and Walters (1964, 7) claim is a satisfactory type of method for the "general run of practical human purposes." This type of agglomerative approach to classification is exemplified in the semantic development of the words used in every day language. With the typological method of classification, a name is given to objects which resemble each other in certain rather ill-defined ways, thus forming a generalized 'type picture.' As each new object is considered, a decision is made as to whether or not the object resembles this type-picture sufficiently to be given the same name. No one or more attributes are necessarily possessed by all the objects in a particular class, but rather these objects show a 'family resemblance' to an imaginary 'type-representative' of the class. The authors contend that the typological method of agglomeration has developed and persisted as a satisfactory method in classification.

What distinguishes agglomeration from logical subdivision, from a philosophical point of view, lies in the specification of the universal set, or the boundaries imposed on the subject matter of attention. With logical subdivision, the universal set is specified by definition and many classes may not have members (Harvey 1969). In grouping procedures, boundaries are determined out of necessity, whereby all classes will have members and any general conclusions made from grouping must proceed by induction. Neither method is better for all purposes; each is adopted for a particular kind of purpose (Gilmour and Walters 1964). The choice of classification method depends on the purpose for which the classification is being made; not everyone may agree with the appropriate method. Harvey (1969) regards the divisive approach to classification as the only effective and logical way of classifying phenomena. Much of the work done in the nineteenth and early twentieth century resorted to logical subdivision. Abler, Adams, and Gould (1971) contend that grouping of like individuals is operationally far superior than logically subdividing a population because it is faster, easier, and all classes defined will have at least one member. Grigg (1965) argues that in practical classifications, the scientist will use both procedures to establish his or her system. Regardless of the approach taken, each classification system represents an attempt at placing order on a complex and dynamic world and is a necessary component of positivist science.

The Fundamentals of Classifying

Logical procedures should be observed when classifying objects into groups. Such fundamentals of formal logic are designed to prevent internal inconsistencies arising within an organizational scheme (Grigg 1965). In classification, phenomena are grouped by reference to their attributes, i.e., on the basis of *properties* they have in common (Harvey 1969). The objects which are to be classed are called *individuals* and the total number of individuals considered in any given classification system is the *universe* or *population* (Grigg 1965). Once the purpose of the classification has been thought out explicitly (the most important fundamental of any classification system), the first stage of classification involves the definition of the individual or the objects to be classed and is referred to in classification theory as the *Operational Taxonomic Unit (OTU)* (Rees 1972; Abler, Adams, and Gould 1971). At the same time, the universe or population of individuals to be classified must also be delimited.

Several important fundamentals are involved in the second stage of classification during which objects are grouped together into classes on the basis of a property they have in common. One such logical principle surrounds the selection of the *differentiating characteristic*, a property which is possessed in some degree by all the individuals. The differentiating characteristic, or principle of division, must be a property of all the objects grouped and must be important for the purpose of the classification (Grigg 1965). The selection of the differentiating characteristic or criteria is usually based on theory or prior understanding (Rees 1972). If the differentiating characteristic is chosen carefully,

then other properties of the individuals will change as the differentiating characteristic changes. Such properties are called "accessory characteristics" and when two properties change in such a manner they are often said to display covariance (Grigg 1965, 466). Rees (1972) identifies three types of differentiating characteristics that may be used: *structural* properties which are those involving only the OTU itself, *relational* properties where at least one other object other than the OTU in question is involved, and *dynamic* properties, or those involving properties of the first or second type at two or more time periods.

Classifications based on one or just a few differentiating characteristics are called *monothetic* classifications in which all the items allocated to one class must share the trait under consideration. However, the selection of one property and the formation of only one category of classes may not give sufficient insight into the things being classified. Classifications based on several characteristics are called *polythetic* and membership in a class does not depend on just one property or characteristic shared by all members but rather, a class or category is established in terms of a set of attributes. The classes of the first category may then be grouped on the basis of a second differentiating characteristic into a second category. The classes of the first category are included within the subclasses of the second category's classes. This procedure can be carried further until all the classes are included within one 'superclass' or class of all classes (e.g., the United Kingdom, as the superclass, can be broken down into nations, which then can be broken down into counties, and further into parishes) (Grigg 1965). Such hierarchical classifications are often called *taxonomies*, whereby the sets of classes or categories are referred to as 'classes of the first order,' 'classes of the second order,' and so forth (Grigg 1965). Perhaps the most renowned taxonomies are those pertaining to the biological sciences, such as the Linnean classification system of plant communities into hierarchical orders of families, genera, species, etc. (Gilmour and Walters 1964).

There is no limit to the number of dimensions that can be incorporated into a classification scheme; two, three, or more variables can be used to define a categorization scheme of two, three, or more dimensions (Abler, Adams, and Gould 1971). The classes that are created will vary greatly in the number of attributes which members possess in common (Gilmour and Walters 1964). With polythetic classifications, some of the members of the class may share most of the appropriate attributes for a class, but not all of them (Abler, Adams, and Gould 1971).

Establishing classifications based on many attributes or characteristics is, as Abler, Adams, and Gould (1971, 158) suggest, "a complicated business." The use of more than one differentiating characteristic or principle of division may produce a hierarchy of classes and the tabulation and processing of the many terms associated with the many attributes may be difficult for the observer. Therefore, traditionally each science's classifiers have favored one aspect over another in their classification efforts. Properties which are used to divide or classify in the higher categories must be more important for the purposes of the division than those used in the lower categories (Grigg 1965). A classification must not skip logical levels; any violation of this rule makes it difficult for the reader to orient him or herself in the classification as a whole and in the sequence of subordination of the classification's objects (Armand 1965). A special form of classification uses an intersecting lattice device in which the generic concept is broken down first by one, then by another criterion. The classes are arranged in the form of a table; the classification according to one criterion is listed along the abscissa axis and according to the other criterion along the ordinate axis. Classifications using intersecting lattices may break down one or both main classes further on the basis of additional criteria, thus yielding third- and fourth-order classes (Armand 1965).

Besides the determination of the differentiating characteristic, some important rules concerning the second stage of classification should be upheld. First, a classification must be exhaustive; every individual must fit into one of the classes (Grigg 1965; Abler, Adams, and Gould 1971). Armand (1965, 22) uses the following example to support this principle that the sum of classes must be equal to the scope of the classified generic concept: "a classification of seas into marginal, inland, and inter-island does not go beyond the scope of the concept 'sea' and, at the same time, includes all possible classes of seas." The second rule of classification states that the classes must be designed so that an individual cannot fall into more than one class; i.e., the classes must be 'mutually exclusive' (Abler, Adams, and Gould 1971). To the questions concerning how many classes should be specified and what should the class limits in each class be depends on the aim of the classification. Where properties used as differentiating characteristics can be measured, the problems of deciding class limits are minimized and classes are necessarily mutually exclusive (Grigg 1965). Quantitative techniques can be used to devise class breakdowns by referring to the measurements made on an attribute. In numerical taxonomy, classification proceeds on the basis of *interval* measurements of similarity among objects (Abler, Adams, and Gould 1971). Numerical taxonomic structures are used to reduce classification to an objective process by minimizing within class variation (Goodchild 1992). Many quantitative approaches to identifying classes are possible, including a generalized distance statistic, principle components and factor analysis, grouping procedures, and discriminate analysis (Harvey 1969).

In classifications of phenomena where differentiating characteristics are *qualitatively* assessed, it is impossible to base a classification on measurable properties simply because the data do not exist. As such, the possibility of overlap in classes is considerable and is difficult to avoid (Grigg 1965). Abler, Adams, and Gould (1971, 157) conclude on the definition of classes with the following: "we classify to clarify... each time we group observations into classes we lose detail in order to gain ease in interpretation... if by trial and error we are able to produce classifications of phenomena which suggest or expose important relationships, then our choices are good choices... our classifications have served their purpose." Nedobity (1986, 349) refers to this principle as "generality in specificity" and defines it as "the most specific event can serve as a general sample of a class of events."

Classification as concept formation is the distinction between categories and individuals as well as between classes and their members.

Making such distinctions is the crux of any classification system. Various integrating concepts such as singularity, uniqueness, and similarity of objects must be accounted for if a classification system is to be logical. Establishing generalizations assumes that there are classes of phenomena about which generalizations can be made. Generalizations would not be possible if all things were considered *singular* since there would be no two examples of any concept. The concept of singularity denies the possibility of a recurrence. Because laws are general, the positivist conception of science does not accept the empirical possibility of singular events (Johnston 1986). However, it can be argued that logically, everything is *unique* (Lewis 1965). The concept of uniqueness implies a single empirical example but not a single causal mechanism producing that example. For instance, a particular set of interactions where two or more laws are operating together may occur only once, thereby producing a unique outcome which is not replicated. But that same set of interactions *could* recur, resulting in the same outcome based on general laws and producing a non-singular event (Johnston 1986).

The basic task in scientific explanation is to search for similarities, especially functional similarities, between unique things (Lewis 1965). General statements can then be made from these similarities and expressed as formal laws. Such laws do not imply that one event is always followed by another, but rather that a functional relationship exists between given determinants (Lewis 1965). Determining whether a phenomenon is unique or general depends on the point of view or on the inherent property of the phenomenon itself. According to Grigg (1965), nineteenth century classifiers were primarily concerned with properties which were inherent in the objects classified. This widely used form of classification involves grouping objects into classes on the *basis of similarity* between objects and is called 'association by similarity.' The nature of similarity is fundamental in classification problems (Abler, Adams, and Gould 1971). In all branches of science the ability to establish generic concepts and scientific laws is dependent on, among other things, the number of identical or essentially similar cases available for examination and classification (Hartshorne 1959). In studying complex interactions, a small number of essentially similar specimens may be found. Scientists often attempt to overcome this difficulty by recognizing categories or types within which differences appear less marked than the similarities.

In the classification of phenomena where a host of independent or semi-independent elements is typically involved, specimens that are similar in all essential elements do not exist. Rather they are similar only in the particular categories chosen and may differ notably in other respects. Hartshorne (1959, 151) notes that a difficult dilemma arises from this issue: "in order to study a significant number of [objects] as similar, we must define the category so broadly as to include individual variations sufficiently great to upset the validity of generalizations based on the assumptions of identical character; if the types are defined sufficiently closely to avoid this danger, we may have but one specimen of each type." Conversely, grouping objects into classes on the basis of a relationship between connected and different objects, called 'association by contiguity,' is what modern biologists have used to classify plants and animals. Whatever the method chosen to measure the similarity between individuals, the aim of any classification is to produce groups of individuals in which within group distance or variance is minimized and between group variance is maximized. Groups are commonly understood as "constellations" of similar objects so that the important concept in their definition is proximity (Johnston 1968, 578). Thus, groups should be homogeneous units and different grouping processes should produce similar results for the same similarity matrix.

In studies of regions, geographers avoid too much uniqueness and too much generality by assembling information into manageable spatial aggregates called *regional systems*, which are areal classifications lying somewhere between maximum uniqueness and maximum generality. Searching for similarities between unique things is something that geographers have done for quite some time, the importance and implications of which have been accentuated by the attempts to formalize these relationships mathematically (Lewis 1965). In grouping land parcels, farms, census tracts, neighborhoods, or large areas, individual observations must be combined on the basis of similarities to form a smaller number of clusters. Each small place on the earth is unique, yet it has combinations of attributes that resemble combinations at other places: "although every place is unique, we can know about places only according to their resemblance or lack of resemblance to other areas" (Abler, Adams, and Gould 1971, 183). Even in the study of particular categories of phenomena such as mountains, geographers have been concerned not merely to study different types but to present full description and maximum interpretation of individual cases (Hartshorne 1959). This concern for individual cases, particularly in regionalization, is geography's own distinctive contribution to science. Although simple in concept, geographers from Hartshorne to Hart have celebrated the power of regional classification to yield insights into complex geographic patterns and processes (Goodchild 1992).

Classification, as the first step in scientific explanation and as an important part of the generalization process, helps us to come to terms with the issues related to a subject matter under study. In our attempts to rationalize why an event is taking place or what the implications resulting from a particular phenomenon are, we must first arrange each observation in context with other events or objects with which it interacts. This activity involves the comparison of unique phenomena and the identification of the fundamental principles and characteristics inherent with the objects. In other words, we organize the phenomena we are trying to understand better in terms of the things with which we are already familiar. Building conceptual frameworks not only allows the identification of characteristics intrinsic to individual phenomena and of similarities and differences among diverse objects, but may facilitate greater understanding of the relationships among diverse phenomena and thus, of their interactions across space and through time.

Chapter 3

GEOGRAPHIC MOVEMENT

Geography is a descriptive science that deals with the surface of the earth, including the climates, plants, animals, natural resources, inhabitants, and industries (Guralnik 1984). All of these events, experiences, processes, and occurrences that can be scientifically described or appraised are defined collectively for the purposes of this dissertation as *geographic phenomena.* Change, or the act of substitution, alteration, or variation (Guralnik 1984), involves dynamic aspects (Allen 1984). Change to an entity causes it to be transformed and can involve one or more attributes (e.g., shape or location) (Guralnik 1984). Langran (1989a, 218) provides an example of how some attributes never change, some attributes change over time, and yet others are measured in the time domain: "The attribute 'address' may be constant to a house but time-varying to a person." Change representing variation of some attribute of a place over time (MacEachren et al. 1992) refers to 'aspatial data' (Langran 1992). If the attribute or value changes continuously over time, it is said to be 'fluent' (McDermott 1982). However, when location of a phenomenon changes, it is said to be *spatially dynamic.*

Spatially dynamic phenomena are phenomena that *move.* All geographic phenomena can be referred to by means of a specific address in three-dimensional earth space (Lowe and Moryadas 1975). When the characteristics associated with a geographic phenomenon change location, *geographic movement* has occurred. Most geographic explanation must contend with the dynamic nature of earth surface phenomena. Physical processes are expressions of movement, such as glaciation and change of seasons (Boehm and Petersen 1994). With human geographic phenomena, movement is purposeful and is often explained in terms of spatial interaction (Lowe and Moryadas 1975). The movement of people, goods, information, and ideas is typically discussed in such terms as migration, trade and transportation, communication, and diffusion, respectively (Hardwick and Holtgrieve 1996). Regions and places are connected by movement or human interaction: "People everywhere interact. They travel from place to place, they communicate, and they depend on others in distant places for products, ideas, and information" (Hardwick and Holtgrieve 1996, 273). Whether a geographic movement involves people, the physical earth, or a combination of the two, it is composed of change in both the temporal and spatial dimensions. The following sections will discuss the inherent properties associated with spatially dynamic phenomena and will look at how, as a concept, movement has been explained within the geographic discipline.

Properties of Geographic Movement

Movement takes time and occurs in space (Tuan 1978); it is predicated by change (Prince 1978). Both human and physical systems change over time and whereas geographers may begin with static descriptions, their explanations inevitably incorporate dynamic phenomena. These dynamic geographic phenomena are characterized by changes in the distributions of its elements and connections (Graf and Gober 1992). The inherent structure of all geographic observations, especially movement, are multidimensional and include theme, location, and time (Sinton 1978). Peuquet (1994) describes these three basic components in her spatiotemporal framework as the what, where, and when of stored information. Space and time dimensions are the essential framework for any geographical topology of movement, particularly topologies of human mobility (Gould and Prothero 1973). The importance or significance each of these attributes has in the understanding and comprehension of the movement will vary with each geographic phenomenon, as well as with scale.

Space

Space is the basic organizing concept of the geographer (Blaut 1972); the spatial point of view is the common bond that cements the geographic discipline (Meentemeyer 1989). Space is many-faceted, ranging from the space of direct experience (*relative* space), to the space of abstract geometric and mathematical thought (*absolute* space) (Parkes and Thrift 1980). The notion of absolute space arose from the attempts of Greek scholars to reduce everything to permanent bodies drifting and colliding in empty space (Blaut 1972). In absolute terms, space is the concomitant of atoms, corpuscles, and absolute things which enables them to be different and to become different (Lucas 1973). Absolute space is a distinct, eminently real, and empirical entity in and of itself; space is purely physical and not abstract or mental. Based on a defined grid system, absolute space is seen as being composed of points, and a time composed of instants, which has an existence independent of the bodies and events that occupy them (Blaut 1972). The location of elements within the grid of the region under scrutiny is that which is considered critical. This is the point of view typically held in conventional cartography, remote sensing, and the mapping sciences. Viewed as a "container" for elements of the earth's surface, absolute space is defined by Euclidian measurements of length, depth, and thickness (Meentemeyer 1989, 164). Euclidian geometry states that a location, or point in space, can be specified by three numbers, or coordinates: latitude, longitude, and altitude (Hawking 1988). These three spatial measurements describe dimensions, which can be imagined as directions at right angles to one another. According to Gleick (1987, 97), the process of abstraction that allowed Euclid to conceive of one- or two-dimensional objects "spills over easily into our use of everyday objects." For example, a road map, for all practical purposes is two-dimensional. It uses two dimensions to carry information of a precisely two-dimensional kind. In reality, road maps are as three-dimensional as everything else, but their thickness is so slight and so irrelevant to their purpose that it can be forgotten.

'Spatial data' are defined as data where each element, or discrete entity, has associated with it a location or series of locations in two-, three-, or N-dimensional space. These locations can be expressed implicitly or explicitly using any system of coordinates. For geographers, as well as professionals in many other disciplines, these locations correspond to points, lines, areas, or a combination of these on the earth's surface (Peuquet 1977). Distance (or length) is the fundamental geographic dimension and spatial objects may be classified according to the number of length dimensions they possess (Martin 1991): zero dimensions (point), one dimension (line), two dimensions (area or plane), three dimensions (surface or space) (Peuquet 1984; Gleick 1987). These four categories or types of spatial data portray the spatial locations and configurations of individual entities (Peuquet 1984). Point data refer to a single data element that is associated with a single location, such as the locations of cities of the United States. The location of line data is described by a string of spatial coordinates which can represent either unconnected isolated lines (e.g., fault lines), tree structures (e.g., river systems), or network structures (e.g., road systems). Polygon data are associated with areas over a defined space and the location of a data element is represented by a closed string of spatial coordinates. Peuquet (1977) discusses three types of polygon data: 'isolated polygons,' where the boundary of each polygon is not shared in any part by any other polygon (e.g., standard metropolitan statistical areas), 'adjacent polygons,' where each polygon boundary is shared with at least one other polygon (e.g., state boundaries), and 'nested polygons,' where one or more polygons lie within another polygon (e.g., contour lines on a topographic map). A fourth category of spatial data is some mixture of the above types, such as line structures mixed with polygon structures (e.g., a state bounded by a river which is both a boundary between adjacent polygons as well as part of the tree structure of a river network).

Spatial entities have individual, unique definitions which reflect the locations of entities in multidimensional space. These definitions are commonly very complex given the tendency of natural phenomena to occur in irregular, complex patterns. Dynamic geographic phenomena may be modeled two-dimensionally, as with the surface of the earth as a plane, or three-dimensionally to describe subsurface or atmospheric phenomena. A fourth dimension could be added for time series data (Peuquet 1984). Physical geographic processes such as tornadoes and hurricanes are good examples of how the movement of an activity may be spatially defined in absolute terms; the succession of spatial coordinates, indicating location and direction, are measured and aid in tracking an entity's movement through space. Viewed in the Euclidian sense, defining the spatial extent of an object's movement can be highly precise and mathematical, especially with the recent emergence of global positioning systems.

Opposing the absolutist doctrine, the relative view of space rejects the idea that space is an entity by itself. Rather, space is viewed as relative or as merely a relation between events or the aspect of events. Concern lies with the conceptual role of space and not with its metrical properties (Lucas 1973). Older than the belief of absolute space, the relativist doctrine of space derives from more pragmatic concepts of measurement. Space is rationalized as bounded to time and process (Blaut 1972) and is seen as a necessary concomitant of other fundamental features such as substance, time, change, and motion, as well as a concomitant to consciousness (Lucas 1973). Like time, relative space is *perceived* through ordinary visual or tactile experience: "if we have any concept of time, then we must have some concept of space" (Lucas 1973, 99). Relative space is inseparable from time, the two forming what is called the "space-time manifold," or simply *process* (Blaut 1972, 43): "pure space is relegated to pure mathematics, and every empirical concept of space must be reducible by a chain of definitions to a concept of process." No phenomenon in the physical world is purely spatial or temporal; rather everything is process. The temporal dimension may be neglected sometimes, but it is always implied.

Geography is a science of certain types of "space-time integrations" (Blaut 1972, 48). In a geographical context, relative space is not defined by Euclidian terms, but rather by the spatial elements and processes under consideration (e.g., migration and community patterns, watersheds, and diffusion of ideas) (Meentemeyer 1989). For example, two areas separated by a barrier may be close in absolute space and very distant in relative space when time, rates, and interactions are considered. Thus, a functional (spatial) process region may be difficult to map in terms of absolute space (Meentemeyer 1989). The spatial extent in which a phenomenon is occurring is not necessarily characterized by its Euclidian distance, but may be measured more on the internal structures operating within that space. For example, in daily trip pattern studies, the 'activity space,' or the area which contains the collection or majority of destinations of a particular individual (Jakle, Brunn, and Roseman 1976), is measurable only to the extent of an individual's perception of space. It is a subspace within the mental map, and frequently tends to be discontinuous (Lowe and Moryadas 1975). In this way, space is measured or defined relatively, where one object's spatial location is defined by that of another. Measurements of space become synonymous with terms such as "near" and "far," or "left" and "right" (Peuquet 1984, 74).

Some views of space incorporate both absolute and relative notions of space. Aristotle theorized space as metaphysical reality, a fusion of empirical perception and an *a priori* form of understanding. Kant viewed all processes not as psychological, but as transcendental where spatial extension is intuitively associated with temporality (Blaut 1972). However, the 'relativistic revolution' had been set in motion long before Einstein's special theory of relativity, which refuted Newton's absolute spatial reference frame. Scientific verification proved that there is no absolute frame of reference with which one may orient oneself in relation to other reference frames (Weissert 1991). By the beginning of the present century, absolute space had been discarded throughout most of science and philosophy (Blaut 1972). Most modern work in geography involves a relative view of space (Meentemeyer 1989).

Measuring the space a phenomenon travels through as it moves in time is an important part in understanding the dynamics of the activity. Space can be measured in several ways, such as metrically with rulers, temporally with clocks (i.e., 'drive time'), or by adapting an arbitrary system of assigning some distance such as degrees of longitude (Lucas 1973). Perhaps an even more basic knowledge about a movement comes from understanding the spatial form or pattern that the phenomenon takes as it evolves and changes with time. Structure and process are not two different things (Blaut 1972); rather "spatial arrangements are reciprocally tied to movement processes" (Abler, Adams, and Gould 1971, 237). According to Meentemeyer (1989), it is from spatial form that most processes are discovered. Spatial forms are represented by arrangements of points, lines, or areas (Graf and Gober 1992). As Haggett (1967) suggests, the mathematical approach to geography allows the conversion of different geographical phenomena into the same class (i.e., streams and highways are treated as line sets), as well as the transformation of geographical phenomena from one class to another (i.e., line sets transformed to density surfaces). Surfaces, like point sets and line sets, form a distinct family of geometrical forms. As we have seen, space can be described in many different ways, but geometrical features are those general features of space that are the same however space is described (Lucas 1973). For example, in defining the spatial extent of an individual parcel of land, the space described in relative terms might include landmarks and relevant locations while the description of the area in absolute terms would probably involve real spatial coordinates and measured planar distances. However, both methods of defining the space yield a description of the physical area as a polygon, comprised of a set of points and lines on a plane.

Interpreted in this fashion, different kinds of spatial phenomena can be seen as basically identical in their spatial structure. Adopting this notion, Abler, Adams, and Gould (1971, 238) devised a classification of movements based upon the "movement geometry" or spatial configuration of the sources and destinations of the phenomena. Ignoring whether or not the movements refer to the human world, the physical world, or a combination of the two, their movement classification displays the basic spatial dimension of moves in sharp relief to one one another where different kinds of moves are seen as basically identical in their spatial structure (e.g., the discharging of people at a subway station is the same kind of line-to-point delivery pattern as water pipes and drinking fountains around the floor in a building). The framework provides a useful spatial or geographic viewpoint with which to describe and understand how things move in earth space. However, to fully comprehend the dynamics of a phenomenon, the influence of time must be accounted for as well. Space and time are "universally and inseparably wed to one another" (Pred 1977, 218), and unless they are taken together, "the geographer's world will retain an air of unreality" (Tuan 1978, 16).

Time

Like space, time is a prerequisite of geographic change (Lucas 1973). The idea of change through time is believed to have been introduced into geography during the nineteenth century largely through the impact of Darwinism (Bird 1989). As Hartshorne (159, 106) notes, "some extent of time is necessary in the primary description of existing interrelationships and rates of change." Anderson (1982, 273) agrees: "Time is a universal attribute of the real world and, hence, of information about the real world." No single approach can reveal the whole nature of time; different approaches bring different aspects of time into prominence (Lucas 1973). In geography, time is logically involved in at least four different ways: as a way of dealing with the present, as a way of describing the direction and frequency of change, as a way of providing historical context in the explanation of existing features on the landscape, and as a way of explaining the causes of development of land surface features. As Hartshorne (1959, 106) stresses, "the recognition that the constant concern of geography is to study phenomena not in themselves nor in their separate variations over the earth, but in the areal variation of the phenomena as interrelated with each other" is the key to a proper understanding of the function of time in geography. The temporal dimension is fundamental in geographical studies if they are to include the

dynamic (Bird 1989). Presumably, time of some sort is the "primary arbiter" of what constitutes a dynamic model (Martin, Thrift, and Bennett 1978, 1). Time becomes "more interesting" when it is used to elucidate 'how' rather than just 'when' questions (Bird 1989, 34).

Haggett (1990) describes four types of temporal change in geography: constants, trends, cycles, and shifts. Both *constants* and *trends* are long-term changes; constants move monotonously in one direction, while trends move in a more general direction. *Cycles* reverse direction repetitively. *Shifts* or discontinuities occur when there is a sudden abrupt change in direction and, like cycles, represent short-term change. The concept of time can also be used in at least four distinct ways in the study of social change: as a social factor in the explanation of changes, as a causal link between other elements, as a qualitative measure of time, or as a quantitative measure of their interplay (Heirich 1964). According to Heirich, an acceptable explanation of change should tell 1) what happened, 2) how it happened, 3) why it happened at that time, and 4) why something else did not happen. Time is relevant to each of these requirements. Time is not a distinct phenomenon, but "exists irrevocably as an element of the tripartite relationship of mass, space, and time" (Barrera, Frank, and Al-Taha 1991, 2). Simply put, we cannot separate time from space (Thrift 1977).

But what is time? Lucas (1973, 3) describes it as "not only the concomitant of consciousness, but the process of actualization and the dimension of change." This 'dimension of change' as Lucas suggests, is the transformation of objects as they occur in space over time and their movements in relation to one another (Peuquet 1994). The time dimension, with its clear past, present, and future, is more accurately regionalized than the space continuum of existence (Abler, Adams, and Gould 1971). Time is a major dimension along which all events occur and around which human life cycles evolve (Kellerman 1989). This serves as a framework by which events, chains of events, and developments can be ordered. This relationship between time and events is what

distinguishes absolute time from relative time. The doctrine of ***absolute time***, which views time as similar to space in that all are "containers for occurrences" (Langran 1992, 27), argues that time is a dimension uncorrelated with the spatial dimension: times are logically prior to events because events can only be differentiated and identified with reference to times. Proposing that time is the quantity of movement, both Aristotle and Newton felt that one could unambiguously measure the interval of time between two events, and that this time would be the same whoever measured it, "provided they used a good clock" (Hawking 1988, 18). Believing that time is absolute and space is not, Newton theorized that if a pulse of light is sent from one place to another, different observers would agree on the time that the journey took, but will not always agree on how far the light traveled (Hawking 1988).

However, Einstein's theory of relativity, which states that the laws of science should be the same for all freely moving observers regardless of their speed, revolutionized Newton's ideas about space and time. Relativity stated that all observers must agree on how fast light travels, but will not agree on the distance the light traveled and, therefore, will also disagree over the time it has taken (Hawking 1988). Einstein showed that time is affected by motion and that time arises from events, rather than that time exists before events (Schlegel 1968). By the 1920s, most scientists had accepted Einstein's premise that time is not absolute, but rather is a fourth dimension that interacts with space (Langran 1992). Lucas (1973, 5) explains: "Time is related to change, and through change to the things that change and the space in which they change." This *relativist* approach to time sees events defining the movement of time (Rescher and Urquhart 1971); events are triggered by other events, not by time (Lightman 1993). Campbell and Olson (1991, 21) further this argument by conceptualizing time as being made up of different strands or "braids" intertwining between entities across scales and over space. So if times do not exist of themselves, but rather are constructed (Parkes and Thrift 1980), how then is time measured?

The problem of quantifying time has tormented the minds of great philosophers far more than its correlative, space (Kellerman 1989). For some, measuring time seems "mysterious" and "suspect to the scientific mind" (Lucas 1973, 4). For others, as Lightman (1993, 127) facetiously suggests, the task can be fatal: "their bodies stand frozen on street corners... in time, these statues are taken to the quarryman, who cuts them up evenly in equal sections and sells them for houses when he needs the money." While the temporal and spatial dimensions can be generally viewed as similar and inseparable, measurements of each are not. Whereas spatial measures are of changes in state between two entities over space at a single time, temporal measures are of changes in state, over time, for a single entity. All time measurements involve movements in space (Kellerman 1989). This fundamental distinction between duration and distance is a proven difficulty in building models of spatiotemporal topology (Barrera, Frank, and Al-Taha 1991). Although time exists, it cannot be measured tangibly like space; rather time is *perceived*. As Abler, Adams, and Gould (1971, 9) explain, time is related to consciousness: "Perhaps our insensitivity to space is related to the fact that movement in space is voluntary whereas movement in time is wholly involuntary. Our inability to control time makes us more sensitive to it." Lucas (1973, 7) agrees: "I cannot conceive of a mind being conscious of something about whom the question 'when?' does not arise, whereas there are many states of consciousness for which the question 'where?' does not naturally arise." Rescher and Urquhart (1971, 152) explain this notion of 'eternal recurrence' as "[going] through everything in exactly the same way again and again and again in a cosmic history that is infinite in both directions (temporally forward and backward)." Essentially, time may be conceptualized or perceived in one of two ways: as continuous or "mechanical time" and as discrete or "body time" (Baker 1989; Lightman 1993, 23).

We are all familiar with *mechanical time*: the continuous, every day time of clocks, calendars, and seasons. Here, standard or universal time is predicated on the natural rhythms of the earth revolving around the sun and the movement of time is predictable

(Lightman 1993). Mechanical references to time in today's society often are in units of hours, minutes, and seconds. Decades and generations are also familiar reference points in the chronologies of personal histories. However, units of time that refer beyond these limits such as centuries, eras, and epochs become more difficult to perceive since their significance at a personal level is often obscured by day-to-day events that take precedence (Hardwick and Holtgrieve 1996). Morse (1996, 29) defines such lengthy periods of 10,000 years or more as "only a tick in time for earth." Fernand Braudel, a twentieth century French scholar, referred to these scales of time as 'geologic' whose "passage is almost imperceptible" and also as a kind of historical time in which "all change is slow, a history of constant repetition and ever returning cycles" (Marwick 1984, 36). In geography, landforms are the most nearly static among all phenomena of areal variation in which the process of change is so slow that little error results from assuming they are static (Hartshorne 1959). Other types of mechanical time 'clocks' are world time, database time, and institutional time. With respect to data, *world time* is the beginning, discovery, change, and extinction of some mappable entity. *Database time* refers to the measured transactions of the data object, such as insertion, mutation, and deletion. *Institutional time* is the chronometric dimension with respect to some institution that has a known direct relation to the mappable entity. Barrera, Frank, and Al-Taha (1991, 4) use the example of a bank deposit to show the interplay of these three dimensions of time:

> "A customer might make a deposit of funds to a bank's after-hours depository at, say, 8:00 pm. The bank would consider the deposit to have been made at 10:00 am, the opening of business, on the following day, while the deposit may be entered in to the bank's databases by an employee at yet another time, perhaps 9:15 am. Thus the same event has been measured at three different times in each of the three contexts (dimensions)."

Febvre, a leading French scholar of the Annales School on history, observed that sixteenth century conceptions of space and time were extremely imprecise and felt that measured or "clock" time was less significant than "body" or "experienced" time (Marwick 1984, 29).

Body time refers to time being internally perceived as discontinuous. Leach (1961,

133) offers this explanation of nonmechanical time: "The regularity of time is not an intrinsic part of nature... it is a man made notion which we have projected into our environment for our own particular purposes." For example, time can be related to human activity, a form of which is composed of segments of movement. Here, *social time* is measured by the frequency, duration, and sequence among socially relevant items such as birthdays and anniversaries (Parkes and Thrift 1980). Leach (1961, 135) describes this philosophy: "Without [celebrations]... all order would go out of social life... we talk of measuring time, as if time were a concrete thing waiting to be measured, but in fact we create time by creating intervals in social life... until we have done this there is no time to be measured." As Allen (1984, 127) theorizes, we cannot characterize events and actions without first specifying a temporal logic: "the only time we can identify are times of occurrences and properties."

As another type of nonmechanical time, *lifetime* is biological and psychological because it provides a basis for experimental orientation by facilitating the sequential ordering of times (activities) into the past and into the future (Parkes and Thrift 1980). Essentially, it provides us with a 'sense of time' which may seem long or short, depending on the background of contrasting events ("for children, time moves too slowly already, yet for the elderly, time darts by much too quickly") (Lightman 1993, 175). The approximate unit of a lifetime is understood by all (Hardwick and Holtgrieve 1996); Kellerman (1989, 7) describes this form of inner perception of time as "a basic tool to organize a series of differentiated occurrences along past, present, and future." In geography, the past is used as an aid in understanding present geography. The manner and degree to which time is important for this purpose varies notably within the discipline, but the "historical dimension of time" is usually combined with the dimensions of space (Hartshorne 1959, 84).

Regardless of what temporal mechanism by which we account for our activities and events that occur around us, there are several characteristics of time with which we

internalize the progression of events. Temporal properties attempt to measure the time involved with a particular event or occurrence, either with mechanical quantifiers of time such as minutes, hours, or years, or with discrete measures such as quick, sometimes, long, or always (Rescher and Urquhart 1971). One such property of time is *direction.* Time always has a direction and as Lucas (1973, 43) explains, to conceptualize time without direction is not time at all: "If we could not order events according as they occurred before or after one another, we could not regard them as readily temporal." Kellerman (1989) likens this notion of time's linearity to water, always present and flowing onward. Time, although theoretically possible at microscopic levels in such disciplines as physics and chemistry, is irreversible at the level of our senses (Porush 1991). Using an allegory of verifying a spatial measurement, Lucas (1973, 4) refers to this irreversible nature of time: "We can measure space by moving a ruler... and checking that all the readings are repeatable... but we cannot take a standard second around, and lay it off sixty times against a minute yesterday, and then against a minute today, and back to check yesterday's minute again." Another characteristic of time is *duration.* Duration, or 'how long,' describes the continuance of an event in a space with some associated change (necessary so as to *know* that time is passing). Duration tackles the continuous, linear nature of change or movement (Vasiliev 1993); it is the 'thematic continuity' in the temporal dimension (Parkes and Thrift 1980); it. As a quantifier of duration, *instants* correspond to real numbers and mark the beginning and end of isochronous *intervals*, another important characteristic of time (Lucas 1973).

Temporal intervals are what distinguishes properties, processes, and events; intervals attempt to quantify the lengths of time between events (Peuquet 1994). Time intervals and durations always begin and end with 'the same thing' - a pulse beat, a clock strike, New Year's Day (Leach 1961). Some see discrete time intervals as a way of modeling chaos, which does not denote true randomness but rather the "orderly disorder characteristic" of complex systems (Hayles 1991, 1). Measuring change on a continuum,

deterministic models may produce what looks like random behavior. However, measuring those same changes from year to year will often uncover behavior that has "an exquisite fine structure" (Gleick 1987, 79). Such is the case with determining next spring's gypsy moth population; many insects have a single breeding season. In a simple model like this one, following a population through time is only a matter of taking a starting figure and applying the same function again and again, year after year. Time intervals can also be used in epidemiology where epidemics such as measles, polio, and rubella tend to come in cycles, regular or irregular. In analyzing records of measles epidemics in New York City over a two hundred year time period, deterministic chaos was found in fluctuations of the Canadian lynx population (Gleick 1987). As seen here, viewing time as a discrete variable instead of as a continuum may sometimes yield greater understanding of a dynamic process in a large complex system by allowing the discovery of patterns in change. Intervals or periods refer to *frequency* or 'how often' an event occurs repeatedly over some longer time interval (Parkes and Thrift 1980), and it is frequency that defines the temporal pattern of events and processes.

Several distinguishing types of temporal patterns occur at various time intervals: homogeneous, majoritative, occasional, and wholistic (Rescher and Urquhart 1971). *Homogeneous* processes occur at all times throughout the interval. With this type of temporal pattern, time is linear and continuous. The frequency is one: the event takes place only once, but is continuous throughout. This idea of 'steady-state' (Peuquet 1994) is apparent in recurrent wave models. For example, certain trends of diffusion phenomena are essentially continuous in time; they are constantly with us and merely oscillate in their prevalence, each oscillation being marked by a distinct peak which may occur regularly on a cyclical basis (Haggett 1978). Kellerman (1989, 41) asserts that the source of linear time is "a unique event not subject to repetition." This concept of non-repetition is described by Leach (1961, 125) in his proposition that life change is irrevocable: "all living things are born, grow old and die, and this is an irreversible process."

Majoritative, occasional, and wholistic temporal patterns, which all describe processes and activities that are discontinuous in time, deal with recurrences. If the frequency of events is recurring or oscillating, it is said to be 'chaotic' and 'random' (Peuquet 1994). *Majoritative* and *occasional* temporal patterns describe such frequencies as activities that occur at *most* and at *some* times throughout an interval, respectively. With these two types of temporal patterns, the frequency is not continuous, but does create intermittent periods of varying frequencies which are unpredictable (Rescher and Urquhart 1971). Majoritative and occasional temporal patterns are noncyclical processes in which a system is continuously being carried into states which are different from all previous states of the system (Schlegel 1968). With these two types of intermittent processes there are recurrences, but there is no cycle and no closure of a sequence (Parkes and Thrift 1980).

Wholistic temporal processes are those in which the interval is treated as a whole with the event not possibly transpiring during any subperiod (e.g., flying from New York to Los Angeles) (Rescher and Urquhart 1971). Cyclical activities are examples of wholistic processes. *Cycles* are activities in which the system repeatedly grows from some initial state, through intermediate states, and then again to the original state (Schlegel 1968); they are "a string of events known as a sequence, which repeats itself and is represented by a closed loop" (Parkes and Thrift 1980, 13). Here time is considered as "a continuous recurring rhythm" (Kellerman 1989, 39). Circadian or daily rhythms are believed to be genetically based (Orme 1978) and occur in response to the alternation of day and night. The rotation of the earth on its axis produces equal, repetitive fluctuations between day and night, one season to the next, phases of the moon, etc. (Doob 1978). This natural repetition serves as a kind of "metronome" (Leach 1961, 125) by which we measure the noncyclical changes of nature (Schlegel 1968). Lightman (1993, 8) also views time as cyclic: "suppose time is a circle, bending back and forth on itself... the world repeats itself, precisely, endlessly." Others note that it is change that is perfectly periodic, not time that is cyclic: "If time really were cyclic, there would not be a recurrence of events

that were qualitatively identical though numerically distinct but, rather, the events would be numerically as well as qualitatively identical... it would be the selfsame event - not the same sort of event all over again, but the very same event just once" (Lucas 1973, 59).

However time is perceived and measured, the inclusion of the temporal element in the spatial process is necessary so that ultimately an understanding of the nature and structure of the processes involved can be advanced (Peuquet 1994). Understanding the dynamics of a spatial process under scrutiny, which may lead to greater insight on the interactions among diverse geographic phenomena, involves recognizing the interplay of the spatial and temporal properties of a phenomenon as it changes through space and time. Of equal importance in interpreting a geographic movement is scale. Variation in scale in either the spatial or temporal dimensions, or a combination of the two, will greatly influence the comprehension of the geographic change that is occurring.

Scale

Movement requires change in both the temporal and spatial dimensions. To register change and motion we need some fixed reference points, both in space and in time. As Prince (1978, 21) suggests, time and space are intertwined with each other, and with scale: "In all events, many different kinds of movement are occurring simultaneously. While the earth rotates and day passes into night, people move from one place to another and they also move within the carriage of the stream that is conveying them." Scale is a geographic variable and is considered as "sacred" to the discipline as distance (Meentemeyer 1989, 164). *Webster's New World Dictionary* defines scale as "a system of grouping or classifying in a series of steps or degrees according to a standard of relative size, amount, rank, etc." (Guralnik 1984, 1269). Scale may refer to the spatial or temporal dimension of an object or process, characterized by both "grain" and "extent" (Turner, Dale, and Gardner 1989, 246). *Grain* refers to the finest level of spatial clarity possible with a given data set (e.g., pixel size for raster data). *Extent* refers to the size of the study area or the duration of

time under consideration. Both of these may be referred to as the *resolution*, or precision of the measurement, and should be labeled that of the coarsest element(s) in the study (Tobler 1988).

'Scale' is a word with more than one meaning (Bird 1989); it is used in many contexts and often connotes different aspects of space and time (Carlile et al. 1989). As with space and time, scale can be of an absolute or relative nature. *Absolute* scale refers to the actual, physical distance, direction, shape, or geometry. *Relative* scale refers to a transformation of absolute scale to a scale that describes distance, direction, or geometry based on some functional relationship (e.g., the relative distance between two locations based on the effort required by an organism to move between them). *Cartographic* or map scale is the degree of spatial reduction indicating the length used to represent a larger unit of measure (Turner, Dale, and Gardner 1989). Cartographic scale is usually expressed as a ratio of distance on a map to the corresponding distance on the earth (e.g., 1:10,000) (Martin 1991; Hudson 1992). As Bird (1989, 22) suggests, cartographically, the definition of scale size may be somewhat confusing: "As geographers, we should be nervous about using expressions like 'large-scale' and 'small-scale,' because large-scale map sheets cover small areas, and to map phenomena on a small scale is to cover a wide area." In most other areas of analysis, *fine scale* refers to minute resolutions on small study areas, and *broad scale* refers to coarse resolutions on large study areas (Turner, Dale, and Gardner 1989). Regardless of its definition, the concept of scale size helps us to understand a geographic phenomenon and its causes and effects more readily.

Scale affects virtually every analytical thought and process, regardless of subject matter. The range of spatial and temporal scales used in all scientific analysis is considerable and varies from discipline to discipline. For example, scale can range in space from the subatomic in chemistry to the intergalactic in astronomy, and in time from millionths of a second in physics to billions of years in geology. Geography, viewed comparatively with other such sciences, focuses more on the intermediate range of

temporal and spatial scales because, as Hudson (1992, 283) notes, "its subject matter is focused on place-to-place relationships involving the human use of the earth." The range of spatial and temporal scales used in geography does vary significantly, however, and spans fifteen orders of magnitude or more (Meyer et al. 1992). Using scale to distinguish geographic data from all other spatial data, Martin (1991, 45) refers to 'spatial data' as measurements which relate to objects existing in space at any scale and 'geographic data' as spatial phenomena occurring in space bounded by the size of a building to that of the earth, or from "the architectural up to global scales." Abler, Adams, and Gould (1971, 12) suggest that the lower end of geography's spatial scale should extend to the *room* within a building where they assert "important activities occur and where competition for space is just as real as at larger scales." The temporal scale can vary in geographical analysis from minutes and hours, such as in journey to work studies, to tens of thousands of years, as used to study continental drift. However, as Hudson (1992, 283) notes, geographers' time scales are "strongly skewed toward the present" and are "more compact than a geologist's, broader than a historian's, and much broader than that of an economist who focuses on contemporary trends."

Each discipline adopts its own *scale paradigm* to describe the range of scales it typically uses. A scale paradigm is a nested series of spatiotemporal configurations, each bounded by the next larger scales and each integrating all the patterns and processes ongoing at lower levels within the hierarchy (Delcourt and Delcourt 1988, 27). Although subjective, the spatial and temporal extents of each of these scale levels are generally referred to, in order from small scale to large scale, as micro, meso, macro, and/or mega. *Micro,* meaning a millionth of a specified unit (Guralnik 1984), refers to scales at the lowest levels of administrative units. Geographical analysis conducted at micro or very small spatial scales are those that examine patterns and movements within and around a room, house, or neighborhood and community (Kellerman 1989). Movement behavior at this scale has been studied extensively, particularly short distance and pedestrian movements (Jakle, Brunn, and Roseman 1976). Changes occurring at micro temporal scales, those that make up the history of day-to-day incidents and are usually analyzed in minutes, hours, and days, are often referred to as short-term or daily events. Micro temporal scales are often used in meteorology, where measurements are rarely conducted for more than a few hours or days (Meentemeyer 1989). However, micro scale analysis in geography has also been suggested to include phenomena occurring with durations lasting up to 500 years and spatial extents up to about 100 square hectares. Generally speaking, micro scale analysis is the domain of interest to the landscape manager, the process geomorphologist, and to some human geographers (Delcourt and Delcourt 1988). Typical earth surface processes operating at the micro scale include tidal currents, frost action, soil creep, movement of sand dunes, and fluvial transport and deposition (Delcourt and Delcourt 1988; Bird 1989).

Meso, meaning middle or intermediate (Guralnik 1984), refers to the scale level between micro and macro/mega in the hierarchy of a scale paradigm. According to Meentemeyer (1989), meso scales are usually the most difficult to define and model of all scales in a paradigm since some phenomena show distinct scale thresholds, such as watersheds in temperate zones which display a very peaked discharge response. Delcourt and Delcourt (1988) suggest meso scale extends in time from 500 years to 10,000 years and in space from one square kilometer to 100 square kilometers. This domain may encompass events occurring over the last interglacial interval and could include plate tectonics, eustatic movements, and cyclones (Bird 1989; Delcourt and Delcourt 1988). Meyer et al. (1991) define the spatial extent of meso scale studies in geography to range from less than a square kilometer (biogeographic analysis of a forest stand), to several square kilometers (geomorphic study of a watershed), to thousands of square kilometers (analysis of a regional drought). Generally, meso scale analysis in geography occurs at regional and intranational spatial resolutions and in temporal domains measured in months and years. Meso scale or medium-term changes involve geographic analysis at the weekly, monthly, or yearly temporal scale and may include life cycle phenomena such as migration. Many geographic phenomena are examined at meso spatial scales including examinations of human geographic movement at the city or regional spatial scale (e.g., trips using mechanized transport, including work, social, multipurpose, and long distance trips) (Jakle, Brunn, and Roseman 1976). Transportation planners, as well as urban and political geographers, may also engage in meso scale analysis.

The highest or largest levels in a scale hierarchy are *macro* and *mega* scales. Often, the two are used interchangeably and mean very large scales within a paradigm. Natural phenomena operating at macro scales may range temporally from one to many glacial-interglacial cycles (10,000 to 1,000,000 years) and in spatial extents averaging in width from 100 kilometers up to 1,000 kilometers such as the physiographic region of the Blue Ridge Mountains of eastern North America. Bird (1989) suggests macro scale levels occur at the national and international spatial levels and include such earth surface processes as solar radiation, water resources, and flood problems. Mega, meaning a million of a specified unit (Guralnik 1984), generally refers to processes occurring in spaces ranging from continental to hemispheric and global and in time periods of over a million years. This scale domain includes the majority of geologic time during which plate tectonics have changed the configurations of continents and ocean basins (Delcourt and Delcourt 1988). Physical geographic phenomena examined at increasingly large spatial and/or temporal scales are long-term changes occurring in geologic time and include atmospheric processes, earthquake cycles, soil development, glaciation, and global climatological processes such as carbon dioxide variations (Prince 1978).

Kellerman (1989) proposes a simple scale paradigm where three dimensions (time, space, and society) yield micro, meso, and macro levels of reference. According to Kellerman, the most studied inter-connections among time, space, and people seem to have taken place at one or more of the extreme edges of the three continuous dimensions. That is to say that the spatial and temporal scales are "loosely associated" and are typically engaged in many geographic societal studies (Langran 1989b). For example, urban planning deals with relatively large areas and long time frames (e.g., communities and years), while behavioral geography generally focuses on smaller temporal and spatial human units (e.g., hours and city blocks). Activity space studies have shown that human activities which are the most routine involve the smallest spaces and are correlated with the shortest periods of time. Conversely, rare unroutine activities, such as changing careers, often involve movement over large spaces or distances and can be so rare as to recur only once or twice in a lifetime (Meentemeyer 1989). Here, time is equated with distance where temporal and spatial scales are paired into distances that could be traversed in time spans (e.g., minute/room, day/city, week/region, year/nation, and life/world) (Langran 1989b).

The linearity between spatial scale and temporal scale is also supported by some earth system processes. As Kelmelis (1991) suggests, physical processes that only occur within minutes also occur at a spatial scale of a few kilometers, such as atmospheric turbulence, while processes such as plate tectonics occur over thousands of kilometers, as well as over millions to billions of years. Processes and phenomena such as glaciation and continental drift involve broad spatial scales and appear to be changing so slowly that very long time scales are needed to observe and model those entities (Meentemeyer 1989). Peuquet (1994, 452) offers the following example, further demonstrating the direct relationship between spatial and temporal scales: "... individual plant growth tends to be a micro scale process since it occurs over a spatial scale of meters or fractions of a meter as well as over a temporal span of weeks. Similarly, changes in vegetation patterns tend to be meso scale processes since these occur over a regional scale... as well as over a temporal span of decades."

As seen with these examples, the "coordinate scheme" for locating events changes with the scale at which the events are analyzed (Holly 1978, 12). It would seem inconsistent to attempt an analysis of events recurring at a macro scale with minutes or hours as the temporal metric; the use of weeks or months might be more manageable. Although there are instances where noncomparative levels of scale are used in an analysis, such as in historical geography where a macro time scale is generally employed while examining the landscape with a relatively small spatial scale, generally scales at which changes occur are largely dependent on one another: "In changing one's spatial perspective by looking at different geographic scales, we concurrently change temporal scale" (Jakle, Brunn, and Roseman 1976, 101). Regardless of what level and degree of association among the scales used, all analyses require the definition or designation of fixed spatial and temporal reference points by which observations and conclusions can be drawn. Determining which temporal and spatial scales to use in the examination of a geographic phenomenon is imperative and will affect the focus, methodology, and results of an analysis.

The scale of analysis is critical in science or any other ordering system (Abler, Adams, and Gould 1971, 37). As Hudson (1992, 280) describes, a successful research design first defines the scale at which the phenomenon of interest can be observed and then selects methods of analysis appropriate for resolving patterns and processes at that spatial-temporal scale: "All fields of study that make empirical observations must consider scale. When the scope of any study is set, decisions are made about what is to be studied in detail and what is to be left in the background. Scale is not a constant in most cases: it is stretched here or compressed there to emphasize what is important at the expense of what is peripheral." Choosing the appropriate scales in space and time in which observations are made and analysis presented will ensure the appropriate formulation and answering of meaningful research questions. Scales are determined by observer-dependent criteria and both analytical (e.g., fractals, Fourier transformation, multiscale ordination) and empirical methods can be used to determine scale (Turner, Dale, and Gardner 1989). Choosing the level that is thought *a priori* best for the problem data may be guided by past experience of that sort of data, by whether our principal objective is synthesis or analysis, or by a political view that gives the determining scale. Some concur that for ecological phenomena a "natural scale" exists that will yield the most information about the phenomena (Carlile et al. 1989, 203). Langran (1992) theorizes that 'common wisdom' dictates that information should be captured and stored at the finest resolution required. Agreement on appropriate scale is not always reached: "As many futile arguments among geographers arise out of different opinions as to the scale at which phenomena should be analyzed as arise in normal discourse because the discussants hold different definitions of critical terms" (Abler, Adams, and Gould 1971, 37-38). Regardless of the scale chosen to confront a problem, the choice may not be as error-free or appropriate as supposed (Bird 1989).

Scales may be inappropriately selected due in part to a host of "determinants and constraints" that economically and logistically restrict the choice of most appropriate scale, such as the size and speed of a spatial phenomenon or process, scales of existing maps, aerial photographs, and remotely sensed images, data handling thresholds (e.g., time, technology, money), mathematical-statistical constraints (e.g., spatial/temporal autocorrelation), or the size of the spatial units (e.g., census tract) (Carlile et al. 1989; Meentemeyer 1989, 171). So constrained is the choice of appropriate scale that sometimes, as Meentemeyer (1989, 171) suggests, "in the end it seems that scales are unconsciously selected and therefore may seem to be entirely arbitrary." Turner, Dale, and Gardner (1989) suggest that in developing the appropriate scale for the phenomenon of interest, it may be necessary to sample processes at several scales in order to identify any scale dependencies. In determining the most appropriate measurement scales to use for different processes or physical properties, it may also become necessary to study the various processes influencing something, thereby introducing different levels of resolution on the scale of observation (Carlile et al. 1989).

In viewing changes, we apply different scales to different kinds of occurrence. As with the spatial dimension, the temporal dimension's scale can range from very short (micro scale) to very long (macro/mega scale). However, unlike the natural progression of increasing spatial scale, scaling time is much more subjective and, as Prince (1978, 22) comments, the definition of time scale is at the discretion of the examiner: "The difficulty with delimiting the categories of time has always been to find suitable descriptions of duration, which could vary according to events while measuring them against a fixed scale. History has no periodic table of contents and no classification of types or species; it has only solar time and a few old ways of grouping events, but no theory of temporal structure." The choice of time scale not only has important consequences for analyzing change, but has implications for the kinds of hypotheses one forms (Heirich 1964). If equal quantitative units such as a month or year are selected, time can be used as an interval scale, the size of which will affect the kind of changes that can appropriately be analyzed. For example, a series of individual events can be clustered into 'episodes' and perhaps into 'cycles.' Perfectly cyclical distributions can represent an important form of steady-state behavior over longer temporal intervals (Peuquet 1994). In defining a temporal level of duration, the difference between 'abrupt' and 'gradual' change is relative depending on the temporal scale used (Peuquet 1994). Furthering this point, Prince (1978, 22) explains how "revolution," which he defines as "a fundamental change accomplished in a short period of time" can describe the "brevity" of the eight month Russian Revolution in 1917, as well as the four-year French Revolution beginning in 1789. The ideal temporal scale for viewing phenomena depends on the phenomena. Phenomena change at different rates, and, ultimately, methods of deriving one temporal scale from another is needed (Langran 1989b).

Qualitative and quantitative changes in measurement across spatial and temporal scales will differ according to how scale is defined; therefore, the definitions and methods of changing scale must always be explicitly stated (Turner, Dale, and Gardner 1990). Sciences dealing mostly with processes (e.g., meteorology) are better able to switch scales than those dealing mostly with phenomena because the size of the phenomena decides the scales (Meentemeyer 1989). Geographers are especially adept at moving from one scale to another. As Bird (1989, 19) claims, "the eyes of a geographer light up when scale is mentioned" given the discipline's great advantage in its ability to "slip smoothly" between scales and compare different levels of approach. This holds true especially for physical geographers who, given the variety of spatial and temporal scales of landscape processes (Baker 1989), have always worked at multiple scales (Meyer et al. 1992). The range of spatial and temporal scales of physical phenomena, such as ecological problems, has expanded dramatically in recent years and many environmental problems require landscape, continental, and even global levels of understanding (Turner, Dale, and Gardner 1989). To a lesser extent, this holds true for most human geographers, who have had to broaden the spatial and temporal extents in analyzing patterns of human interaction given the rapid technological advancements in communication, information, travel, and trade.

Geographers typically focus on a particular range of scales in their analyses so as to ensure that conclusions drawn from a study are well matched to the economic, social, and physical processes known to underlie observed patterns (Hudson 1992). Variations in both temporal and spatial scales largely affect the identification of patterns; trends or patterns discernible at one scale are often invisible at another (Kellerman 1989). For example, examining a single volcanic eruption may yield information about that particular volcano such as the rate and range of the lava's movement. But by expanding the spatial scale or the geographic reference, other volcanic eruptions elsewhere could be included in the analysis. Doing so may reveal insights and patterns to volcanic activity in general, thereby allowing further comparative analysis of causes and effects and permitting predictive modeling to be conducted. Changes in the temporal scale may also reveal very different synopses of an activity. Looking at the patterns of migration over a period of several years or perhaps even centuries will reveal identifiable patterns of settlement on the landscape and may lead to insights on the causes and effects of the migrations. In contrast, examining residential migration within a small temporal scale of a month or a year will yield an entirely different set of questions and conclusions about human movements. Simply put, "geographic phenomena look different at different scales" (MacEachren et al. 1992, 131).

Changes in scale also change the important, relevant variables in an analysis. Parameters and processes important at one scale are frequently not important or predictive at another scale (Turner 1990). The value of a phenomenon at a particular place is usually driven by causal processes which operate at different scales (Meentemeyer 1989). Interactions between components occur at different scales (Campbell and Olson 1991). For example, coupling between the surface of the earth and atmosphere occurs across a wide range of temporal and spatial scales, each influencing each other. Specifically, evapotranspiration occurs within hours and affects the atmospheric state (i.e., net radiation at surface, precipitation, temperature, etc.) which in turn affects photosynthetic and transpiration rates of the surface vegetation and hydrologic cycle, which eventually (decades to millennia) affects terrestrial landscape structure and underlying soils (Hall, Strebel, and Sellers 1988). As the dimensions of time and space change, cause and effect relationships may be obscured or even reversed, and the system or process itself may be described differently. For example, in describing the three-fold scalar division under capitalism, Bird (1989) describes capitalism at the state level as an 'ideology,' at the world system as 'reality,' and as 'experience' at the local scale.

Generally, fine scales (e.g., individual level) determine cause and effect, while models for broader scale patterns result in less predictive accuracy at specific points or places; aggregate scales generate hypotheses and are useful for generalizations. Often, extrapolation of fine scale measurements for the analysis of broad scale phenomena is necessary as is in many ecological studies (Turner 1990). As the scale of study advances toward the meso and macro/mega scales, more generalization becomes necessary, involving the judicious selection and omission of detail. Given that geography is primarily an empirical science, generalizations (e.g., models) are only as good as the finest-grain spatial data available (Meentemeyer 1989). Bird (1989, 26) compares the regional geographer to a "painter" or "novelist" who must selectively interpret a vast and

complicated landscape from numerous accurate descriptions of every small area that rests within the landscape. Information is often lost as spatial data are considered at coarser scales of resolution (Turner 1990). Often times, generalization and problem-solving may require a focus on the understanding of the context and consequences of a single event (Bird 1989). In ecology, a variety of processes that have been studied on small areas have important ramifications on the landscape scale that have not been well-studied. For example, the dieback process in certain forests, which may be caused by anthropogenic causes such as air pollution and the introduction of exotic pathogens, or by 'cohort senescence' (i.e., aging of particular stands), causes certain alterations such as the forest's diversity, age-class structure, and patch structure. These alterations, while important in themselves, also have important ramifications for the spread of subsequent disturbances, such as decreased habitat for some indigenous species. Thus, better understanding of landscape processes might come from 'scaling-up' from more detailed studies that have already been completed on smaller land areas (Baker 1989).

Extrapolations from higher levels of resolution to finer scales also occurs in the scientific method, geography not withstanding (Meentemeyer 1989). As Martin (1991, 59) explains, the key difficulty with this method is that "there are a very large number of possible areal units which may be defined, even with the imposition of certain size and contiguity constraints, and none of these has intrinsic meaning in relation to the underlying distribution of population." Referred to as the *modifiable area unit problem*, once data transformation has taken place, the characteristics of individuals cannot be retrieved from the aggregated data. Problems can arise from inferring that statistical patterns at the macro scale are replicated at the meso and micro scales. Such a "clashing of scales" has become known as the *ecological fallacy* where conclusions about individuals from grouped data are incorrectly deduced (Bird 1989, 26-27). This problem of scale involves differences in inference and relevant variables caused by different scales or hierarchical levels (Meentemeyer 1989). Different scales of approach may eventuate in different

results. When the scale of mesh used to catch and present the spatial data (and affecting the results) is chosen with malice aforethought, situations such as gerrymandering of electoral districts arise (Bird 1989).

Scaling processes, particularly landscape ecological phenomena, from one level to another is not a simple mathematical progression as with Newtonian mechanics and the Euclidian geometry on which it is based (e.g., whether the sides of an isosceles triangle are two centimeters or two kilometers long, the triangle still has the same properties) (Golley 1989). Rather, for most complex systems and irregular forms, statements made about one scale level do not hold true for another (Hayles 1991): "We cannot move as a boat builder does from a model to the full sized craft... scaling up or down requires that the systems at the two levels be similar in the properties of interest" (Golley 1989, 72). The significance of emergent properties appear when moving from one level to a higher in a hierarchy. Each level has its own unique properties that are not derived by mere summations of the disaggregate parts. Scaling up will not yield these emergent properties; rather, they can be known only by direct study of the process of the system at that level (Hayles 1991). Golley (1989, 71) uses ecological processes such as flows of water, nutrients, and pollutants and the response of the biota to these flows to demonstrate that although all are linked with one another, there is great difficulty in moving from one level to another and comparing results: "...it is not clear how we can move from small scale systems such as fields and farms to regions and nations, especially when we are considering the impacts of air and ground water pollution as they interact and affect crop production and human health."

The mechanisms that relate phenomena at different scales are poorly understood (Langran 1989b). The identification of guiding principles that allow researchers to combine data and models at different spatial and temporal scales and to extrapolate information between scales remains a challenge. Turner, Dale, and Gardner (1989) suggests four guidelines for making predictions across more than one scale: the spatial and temporal scale of the process must be identified, the shift in relative importance of parameters at different scales must be understood, appropriate methods to translate predictions from one scale to another must be developed by identifying constraints that are important at each scale, and finally the methods and predictions must be empirically tested across multiple scales. The importance of scale in scientific analysis, particularly in any geographical explanation, cannot be overstated. Accounting for scale in all dimensions of a phenomenon under investigation will help in the understanding of the dynamics of that phenomenon as it changes its location in space and time.

Treatments of Movement in Geography

"The essence of geographic inquiry is a sensitivity to the worlds of place and space" (Graf and Gober 1992, 234). Both human and physical phenomena interact with one another creating complex, if not distinct, patterns, arrangements, and locales on the landscape. All geographic explanation attempts to describe in some fashion patterns, arrangements, and locales in the landscape of interactions among human and physical phenomena. Geography is fundamentally concerned with asking and answering questions about phenomena tied to specific locations on the surface of the earth (Martin 1991). Such explanations always include descriptions of space and, as Hardwick and Holtgrieve (1996, 272) note, "geography occurs not only in space, but in time." Changes in space and time often include changes in scale. All three of these dimensionalities surrounding a geographical phenomenon interact with one another and it is these spatial, temporal, and scalar changes that compose a phenomenon's dynamic nature and are at the heart of that phenomenon's explanation. Given this natural 'tendency' of most geographic explanation to include, no matter what the intent, aspects of change, how has the discipline as a whole acknowledged the significance of dynamism in geography? Using the six fundamental questions of who, what, where, when, why, and how, the combinations and permutations of which "exhaust our curiosity about our experience" (Abler, Adams, and Gould 1971, 12),

the role of movement in geography will be examined.

Movement as a Central Theme

Geography is "an eclectic subject" that ranges from the physical sciences through the social sciences to the arts and humanities (Boehm and Petersen 1994, 211). It is this "breadth of topics and divergent points of view" that often has been the focus of criticism of the field of geography (Meentemeyer 1989, 163). Perhaps such criticisms are what have spawned a national reform movement in defining geography curriculum in this country. *Guidelines for Geographic Education* (Joint Committee on Geographic Education 1984) marks the beginning of several conceptual frameworks designed to improve education and understanding of geographic principles, concepts, and themes. *Guidelines* did not claim to represent a 'new geography,' a new approach to geography, or a new geographical taxonomy, but rather served as a vehicle to convey the core ideas of geography to the general public. Written in 1984, the document contains scope and sequence in geography with suggested learning outcomes for elementary and secondary grades, outlines basic social studies skills, and suggests strategies teachers can use to analyze geographic information that students, in turn, can use to study and eventually find solutions to social questions or problems. As an alternative to the "detrimental, but unfortunately persistent" habit of teaching geography through rote memorization, *Guidelines* stresses higher level concepts of geography that allow students to learn about the critical interface between physical and human environments (Boehm and Petersen 1994, 211).

The most enduring contribution of *Guidelines* has been the articulation of five fundamental themes of geography: location, place, relationships within places, *movement*, and regions (Joint Committee on Geographic Education 1984). Although application of the fundamental themes has been uneven in classroom practice, with some teachers using the five themes in an overly simplified manner or even erroneously, widespread acceptance of the framework by teachers has been crucial in reestablishing geography either as a

free-standing course or as an integral part of recently revised social studies curricula (Boehm and Petersen 1994). The five themes, as a tool for organizing the content of geography in a convenient, widely adoptable format, can accommodate virtually all conceptual frameworks currently in use by teachers of geography. The five fundamental themes have become an integral element of social studies education and have appeared in most, if not all, geographic textbooks and social studies programs as a context for geographic education.

In 1992, the National Assessment of Educational Progress, a geography consensus group, identified the principal role of *Guidelines'* five themes to be "for teaching" and devised an alternative framework that organizes the content of geography "more realistically" into three categories to be used "for assessment:" space and place, environment and society, and *spatial dynamics and connections* (Boehm and Petersen 1994, 212). Another framework developed during this period of national reform of geography, *Geography for Life* lists and outlines eighteen content standards to divide the discipline into topics that teachers can use. Movement is involved in twelve of these eighteen national geography standards. For example, standard nine states: "the geographically informed person... knows and understands the characteristics, distribution, and migration of human populations on earth's surface" (Boehm and Petersen 1994, 212). Movement is also associated with such principles and elements as ecosystems, cultural patterns and mosaics, and geopolitical cooperation and conflict (Hardwick and Holtgrieve 1996). Throughout the national reform movement in geographic education the concept of movement as an important, central theme within geography has persisted.

The Who or What of Geographic Movement

'Who?' and 'what?' are questions of a human and nonhuman phenomenon's identity, respectively. *What* questions typically deal with semantics (i.e., word definitions, essence, occurrence, or combinations thereof). *Who* questions are special cases of what and

how questions; they may either be disguised what questions or hidden how questions. After some vocabulary has been acquired, who or what questions are usually how questions concerned with the uses to which things can be put (Abler, Adams, and Gould 1971). If movement has been classified or categorically identified within geography, it has been by who or what is moving across a landscape. Traditionally, theories of movement have been defined on the basis of their subject matter; as described in the *Guidelines for Education*, people, ideas, and materials are the basic subjects that often change location over time (Joint Committee on Geographic Education 1984). Typically these subjects of geographic movement have distinct process names associated with them, such as *migration*, which refers to the movement of people. The movement of ideas, innovations, or disease are often explained with the theory of *diffusion*. *Trade* refers to the movement of goods and commodities. Besides phenomena that involve humans, movement also occurs in physical or non-human geographic processes, such as *glaciation*, *volcanism*, and *hydrology*. *Regionalism* can be said to also involve movement; the spatial extent of a region (i.e., its boundaries), and how these change and evolve over time, are at the heart of the description and explanation of a region.

Lodged within these phenomena are fundamental elements about the movement itself, such as why, where, when, and how a movement occurs. Explanation within geography has traditionally centered on one kind or subject of movement with discussion concentrated on one of these process elements. For example, the subject of people moving is often discussed under the process heading *migration*. Within this larger framework lie several avenues for further explanation, such as the kind of migration, origins and destinations, length of time for the migration, the nature of the migration, what instigated it, and what consequences it has on the subject, the landscape, and the interaction between the two. Geographic concepts associated with this movement and that address some of these questions are migration fields, from-to tables, push-pull factors, modes of transport, and distance-decay effects (Jakle, Brunn, and Roseman 1976). The geography of

movement often becomes the description of people moving themselves, their products, and their ideas across the earth.

The Where of Geographic Movement

Questions of a phenomenon's occurrence (i.e., 'where?' and 'when?') are questions concerning past or future events (Abler, Adams, and Gould 1971). In all geographic analyses of phenomena involving movement, one fundamental line of inquiry is to ask *where* the spatial change is occurring. Sometimes knowing the exact location is a necessary part in the examination and interpretation of the phenomenon. For example, in many human migration studies, an important aspect in understanding the movement is knowing where people moved from and to what location they have moved. Knowing these spatial points of origin and destination allows closer examination of these locations so as to offer insight and explanation of the migration itself such as why the phenomenon is occurring, what spatial patterns have been and are likely to be formed, and what effects these human movements have on these locations.

In other geographical analyses, particularly involving humans, study usually begins with the notion that location is space (Parkes and Thrift 1980). Here, the important element in examining a movement is not necessarily knowing absolute geographic locations, but rather is understanding the relative spatial structures of the movement, such as distance affected or characteristics of the landscape. For example, in defining areas affected by gypsy moth defoliation, it is not imperative to know the exact boundaries of the region to understand the general pattern of the spread over time. Interpreting the spatial characteristics of a movement, regardless of the level of specificity, is a crucial and inherent aspect of understanding a geographic movement.

The When of Geographic Movement

Spatial change or movement across space requires change or passage of time. Despite the inherent nature of time and space in geographical movement, examination of time has not been given the same significance as space (Parkes and Thrift 1980). This may be due largely to the way time is measured. Whereas spatial change can be defined in both absolute and relative terms of distance and direction, temporal change measurements are usually based on relative terms only. Nonetheless, the temporal dimension has been incorporated into geographical analyses. 'Time-geography' is largely the result of attempts by geographers such as Hagerstrand, "to develop a model of society in which constraints on behavior can be formulated in the physical terms (location in space, area extension, and duration in time)" (Parkes and Thrift 1980, 243). Time-geography accepts the notion that space and time are universally and inseparably tied together and that examinations of human organization of the earth's surface, human ecology, and landscape evolution cannot separate the two dimensions (Pred 1977). The basic premise of most time-geography analyses deals with the time-space 'choreography' of an individual's existence at daily, yearly, or lifetime scales of observation (Pred 1977). The time-geography framework defines three kinds of constraints on an individual's movements: capability constraints (physiological necessities), coupling constraints (due to the bounded togetherness of individuals, tools, and materials at given places at given times), and authority constraints (legal or other limitations and comfort of access) (Thrift 1977). Time-geography specifies the necessary conditions for virtually all forms of human interaction (Pred 1977).

The conceptual base of time-geography considers both space and time as resources. Space-time budget studies are based on this notion of resource allocation and recognize that human activities take time that can be measured in physical time units (Thrift 1977). In analyses of space-time budgets and activity spaces, the time it takes to perform tasks is empirically observed in various social and environmental settings. The methodology

usually involves a selected sample of people who fill diaries detailing their activities and the length of time required to fulfill them. The activity space, or daily trip patterns of a typical individual, is usually dominated by movement within and near the home, movement to and from regular activity locations, and movement in and around those activity sites (Jakle, Brunn, and Roseman 1976). Some results of these studies can be beneficial for planning and decision making by indicating how activities are and can be performed, and what impact new innovations have on these activities. For example, Forer and Kivell (1981) analyzed time-budget data of housewives in Christchurch, New Zealand who did not own a car. By identifying windows of free time during a housewife's day, the actions and potential activity spaces of individuals in four suburbs were delimited and the variations in access to, and choice between, facilities in these suburbs were identified. Essentially, despite spatial constraints on bus-dependent housewives who could not enjoy large expanses of the city in which to seek out and visit facilities, in some instances there was an abundant choice of facilities because of an above-average provision of facilities in the surrounding neighborhood. The authors concluded that public transport differentiated access to facilities, yet marginally affected the final determination of a housewife's available options.

The Why of Geographic Movement

Another way of detailing a geographic movement is to ask why it occurs. *Why* questions can be divided into two categories: true why questions and how questions in disguise. According to Abler, Adams, and Gould (1971, 12), "true why questions, whether asked about human or physical phenomena, reduce ultimately to theology or metaphysics." The authors further claim that "spatial arrangements are reciprocally tied to movement processes;" that is to say, all movements create spatial structures, and once established, such spatial arrangements influence subsequent movements (Abler, Adams, and Gould 1971, 237). For physical geographic processes, movement or spatial change may

occur due to human intervention, such as the redirecting of a river's flow, or may be caused by natural processes or presences such as wind or plate tectonics. However, explaining why things move in the human world is to refer to the ideas of spatial interaction.

Many models of spatial interaction attempt to explain the aggregate flows of people, goods and services, or information between places (Abler, Adams, and Gould 1971; Jakle, Brunn, and Roseman 1976). The interaction of flow among a set of places is an integral part of geographical analysis; the concept is broad enough to encompass several major areas within geography (Morrill 1978). Ullman's question "what makes objects move over the earth's surface?" arguably encompasses all geographic theory because it is difficult to avoid the notion of movement when explaining how an object acquires its location (Bunge 1966, 112).

In providing explanation for the conditions of interaction, particularly material interaction of goods or people, Ullman (1956) proposes a three-factor system: complementarity, intervening opportunity, and transferability. All commodity and service movements can be evaluated in terms of complementary supply and demands areas, presence or absence of intervening opportunities, and the transferability of the goods and services (Abler, Adams, and Gould 1971). Every population movement from room to room or from continent to continent, ultimately depends on human needs and desires, and on place to place *complementarities* (Abler, Adams, and Gould 1971). Information (i.e., new facts, data, ideas, and routine communication) flows from place to place, moving from places of production to demand areas. A notion of minimal movement underlies the concept of *intervening opportunities*, as movement tends to be generated only where no sources of supply are available between the two places or regions. *Transferability* refers to the technology needed to overcome distance friction. Historically, fresh fruit was far less transferable than manufactured goods; the friction of distance has been greatly reduced by modern (refrigerated and fast) transport.

Expanding upon Ullman's spatial interaction model for explaining some forms of

human movement, Bunge provides a reclassification of Ullman's movement theories. Reducing all movements to their most abstract level, Bunge (1966, 113) states that the four traditional types of movement theories (economic, electric, fluid, and kinetic gas, all of which are based on subject matters of water, people, electricity, and goods) are an "unsatisfactory organization because discussion of the subject matter and the mathematics operating the theory mingle awkwardly." To remedy this "traditional confusion," Bunge incorporates four additional generic concepts into Ullman's spatial interaction theory: duality (real flows, incentives, and potentials), conservation of matter (accounting for quantity of phenomenon), routes, and backhauling (unnecessary and irrational movement). By relating these seven qualities of movement to the four traditional types of movement theories, Bunge proposes a reclassification of all movement theories based on three fundamental dynamic structures: routing theories (theories involving finite mathematics), theories involving two-dimensional phenomena (nonstatistical, areally continuous theories), and theories involving a combination of the two (statistical theories). Bunge concludes that since the generality of these three classes of movement theory increases from route to continuous to statistical, it can be stated that route theory is a subset of continuous theory, which is a subset of statistical theory. While integrating key elements of Ullman's spatial interaction theory which focuses on explaining why a phenomenon moves, Bunge (1966, 130) rationalizes all movement theories in terms of the "spatial separations of techniques and understandings required to operate these theories." This change of focus from *why* a movement occurs to one that incorporates *how* one studies a movement introduces a movement's spatial configuration or form.

The How of Geographic Movement

How questions are often considered the most important questions asked because they lead to explanation. We describe how things move in order to understand movement laws, and because we want to predict and control social and natural events (Abler, Adams, and

Gould 1971). 'How?' may be a question of existence, process, utility, or policy. When asked about processes themselves, how questions treat sequences of events as a single event and are focused on the relationships between events rather than on the events themselves (Abler, Adams, and Gould (1971). In questioning the utility of how things move, we may think of what is it that is assisting in the motion itself; we classify based on different kinds of carriers (Prince 1978). Carriers for movement in non-human or physical geographic phenomena are natural processes such as atmospheric pressure, plate tectonics, gravity, and orbits. These carriers for human movements may be the people themselves, or some mode of transportation such as automobile, train, or airplane, with which they move themselves, their goods, and their products. Another mode of transport in human geography is the electronic highway with which ideas, news, and communication are spread via telephone lines, satellites, and radio signals. Utility questions of how things move are often resolved in terms of modes of transport, rates of speed, and efficiency.

Asking 'how?' about a movement can extend to include questions about the structure of spatially dynamic geographic phenomena. Shifting attention from the actors and activities of movement, as well as whether they refer to the human world, the physical world, or both, Abler, Adams, and Gould (1971) devised a classification of all movements based on the geometric form of the origins and destinations. The authors stress that the building blocks for movement models are the points, lines, areas, and volumes among which movements occur. Their classification, which considers the permutations of these four spatial structures and details sixteen different classes of movements and spatial interactions, is a useful way of breaking down the complexity which exists in the almost indefinite number of movements that we observe around us. The basic spatial dimensions of movements are displayed in sharp relief to one another and, interpreted in this fashion, different kinds of moves can be seen as basically identical in their spatial structure. Such a framework is important for the description and understanding of how things move across three-dimensional space.

The Importance of Movement in Geography

Explanation of geographic phenomena often involves the description of *change*. A phenomenon may change in regards to its aspatial attributes (e.g., the land use of a particular parcel of land is rezoned from agricultural to residential), its spatial attributes (e.g., annexation of an adjoining land parcel to an existing property), or in both attributes (e.g., subdivision of an agricultural parcel of land into fifty residential lots). Dynamic geographic phenomena then, are spatial phenomena that change in attribute or non-spatial phenomena that change location over time. It is important to note that both are 'geographic phenomena' (involving location) even though the phenomena themselves may be either spatial or non-spatial.

Whether movement or spatial change is the primary focus of geographical thinking about a phenomenon or whether it is simply part of a phenomenon's description, the principles of movement are vital components of all geographical explanation. Willmott and Gaile (1992) suggest that geographers should turn their attention from statistical issues towards concern about modeling intrinsically geographic systems and processes and to understanding geographic dynamics. Declaring movement as a theme in geography was the first step towards this new perspective.

We should now move forward and dissect the underpinnings of geographic movement. If commonalities could be discovered that govern geographic movements, such principles would provide a wealth of information about many geographic processes, and would not only aid in greater understanding of a particular phenomenon, but also of geography as well. Understanding the temporal and spatial complexities of phenomena that move over the landscape not only facilitates greater comprehension of an individual phenomenon under study, but leads to new ideas and insights about, and understanding of, the interconnections and interactions among other geographic phenomena.

Chapter 4

A CLASSIFICATION OF GEOGRAPHIC MOVEMENT

Given that classification is a method by which geographers provide differentiation and comprehension of diverse geographic phenomena, and given that "geographers are interested in the relationship between the space in which the event is occurring and the time it takes for the event to occur" (Vasiliev 1993, 2-3), a *classification of geographic movement* is presented (Figure 4.1). The classification organizes geographic phenomena by how they move through space and time; that is, by the *description* of the movement itself. Spatially dynamic geographic phenomena are placed in categories based on the spatial and temporal patterns or forms they exhibit as they move. In effect, the classification does not necessarily describe the pattern of space and time of the objects *per se*, but rather describes the patterns of the movement of the phenomena; that is, the interrelationships of the changing spatial and temporal characteristics.

Geographic movements are broken down by characteristics of change in space and in time. Spatially, all geographic data can be described by points, lines, areas, and volumes. Traditionally, geographic classification has involved the subdivision of all subjects into one of these four spatial object classes and has proved useful as an organizing concept for discussion of spatial phenomena (Martin 1991). The classification presented incorporates these four fundamental spatial features and offers that a geographic movement may be described as being a *point*, *linear*, *areal*, or *volumetric* movement. In describing the movement itself, the motion may be a *point* movement, where the object is observed at two or more locations and perhaps the change between these locations is examined. With these types of movements, the importance of the spatial change lies in the description of the relationship between the two or more points of locations; that is, the description of the

Temporal Characteristics

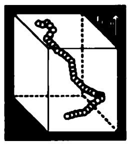
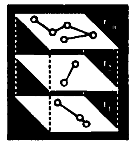
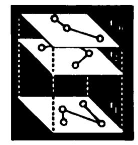
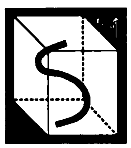
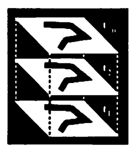
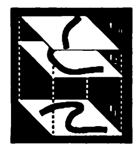
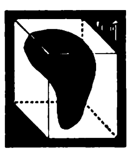
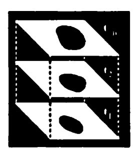
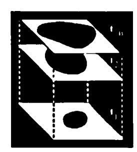
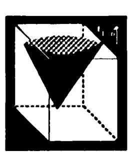
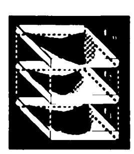
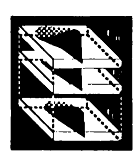
Spatial Characteristics	continuous	cyclical	intermittent
point	 Class 1 *vehicle navigation* *monitored individual movements*	 Class 2 *wildlife migration* *recurrent human mobility*	 Class 3 *irregular human mobility* *volcanic and seismic activity*
linear	 Class 4 *electronic communication* *revolution of the earth* *jet streams, water channels* *a hurricane, a tornado*	 Class 5 *hurricane and tornadic activity* *mass transit* *regular route services* *regular trade and commerce*	 Class 6 *specialized route services* *irregular trade and commerce* *exploration*
areal	 Class 7 *colonization* *diffusion of innovation, culture, and disease* *acculturation and assimilation* *regional boundary changes* *forest fires*	 Class 8 *regional boundary changes* *gypsy moth defoliation* *diffusion of disease*	 Class 9 *regional boundary changes* *desertification* *military deployments*
volumetric	 Class 10 *continental drift, volcanic eruption, earthquake, tsunami, glaciation, rock transformation, soil creep, blowout formation, hydrologic cycle, atmospheric motion, rotation of the earth*	 Class 11 *ocean tides* *beach recovery* *El Nino* *flooding* *pollution*	 Class 12 *pollution* *mass wasting* *volcanic eruptions* *earthquakes*

Figure 4.1 A Classification of Geographic Movement.

linkage between locations. Point-to-point movements are interactions that take place between two locations and occur over non-contiguous space (Campbell and Olson 1991). Interactions occurring over contiguous space may be described as linear, areal, or volumetric. With *linear* movements, movement travels along a path or route such as a road or river and the motion may be described with a line. *Areal* movements are those movements that describe a spread or encroachment. With this spatial classification category, a phenomenon's movement occurs across a surface and the affected space results in a contiguous area or region. *Volumetric* categories of movement describe motion that occurs in three spatial dimensions and includes those geographic phenomena that evolve and change shape in volumes, such as in air or in water.

This classification recognizes that spatially dynamic phenomena are also dynamic temporally and that all movements may be described in terms of a phenomenon's duration, date, and rate. Geographers are generally most concerned with the periodicity of an event and thus duration is a key factor in understanding a phenomenon's temporal characteristics. If a phenomenon moves uninterrupted throughout a period of examination, then it is said to be *continuous*. If the movement is discontinuous during examination, then the motion stops periodically or is said to fluctuate. If such fluctuations are sporadic or irregular, then the motion may be described as *intermittent*. With this temporal class, the movement occurs off and on, the frequency of which is unpredictable and episodic. If the frequency of movement is predictable and regular, then the phenomenon may be said to exhibit *cyclical* patterns or fluctuations in its periodicity. Fluctuations in time that are based on the changes of the day and season are regarded as cyclical temporal classes in this movement classification.

Using these three different descriptors of time (i.e., continuous, intermittent, and cyclical), in conjunction with the four spatial descriptors of geographic phenomena (i.e., point, linear, areal, and volumetric), the following classification presents twelve unique categories of geographic movement. Examination of each movement class within this

organizational matrix includes detailed discussion of the dimensional characteristics associated with each category and highlights of particular geographic phenomenon exemplifying each movement class. For the purposes of this dissertation, variations in either or both the spatial and temporal characteristics can be accounted for by using four simple conventions about scale: micro, meso, macro, and mega. Each of these scale levels are described using "basic hierarchical labels" for the time and space dimensions, such as 'seconds,' 'hours,' and 'years' and 'neighborhood,' 'state,' and 'country,' respectively (Lloyd, Patton, and Cammack 1996, 182). Geographically, scales of interpretation may range from seconds and/or feet upwards to include phenomena occurring over millions and billions of years and/or involving the entire planet within its solar system. *Microscale* analyses use the lowest order of administrative unit and range in time from less than a second up to a day or so and in space from the size of a room to that of a neighborhood. The microscale is typically the domain of interest for studies on individual trip pattern behavior and on highly localized phenomena such as tornadoes. The *mesoscale* domain extends temporally from several days up to a couple of years and spatially from areas the size of towns up to those of metropolitan areas. Seasonal activities generally fall under the mesoscale domain, which is the typical scale of interest to the landscape ecologist. The temporal and spatial extents of the *macroscale* domain range from tens to hundreds of years (i.e., decades to centuries) and from intranational to national, respectively. Life-cycle events are often examined within the scope of macroscale analyses. The largest scale domain, the *megascale*, encompasses phenomena occurring over thousands to millions, even billions of years (i.e., 'geologic time'). Megascale space ranges from continental and hemispheric to global and beyond (universe).

Many geographic phenomena are interpreted at only one particular level of scale that is typically employed over and over again in subsequent analyses. While the actual precise levels of scales may alter from one geographic examination to another, relatively speaking, each phenomenon is usually viewed in a similar spatial and temporal context. For

example, diffusion studies almost exclusively use areas as their spatial unit of analysis, and humans are not usually interpreted *geographically* as volumetric entities but as point objects in space. The perspective adopted in this classification considers the general models of geographic analyses that have traditionally been applied to geographic phenomena. Using Weibel's (1995, 259) suggestion that "ideally, spatial data should be analyzed and viewed at the level of scale at which the modeled phenomena and processes are meaningful and best understood," the classification is dependent on the spatial and temporal scales with which geographic phenomena are typically examined. For example, while some scientific inquiry may examine gypsy moth defoliation in 'real time' as a phenomenon occurring at very small spatial and temporal scales, *geographic inquiry* generally views the phenomenon at increasingly larger scales, both temporally and spatially.

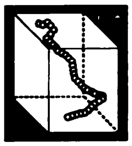
However, some geographic phenomena may be interpreted using a multiplicity of perspectives and can, therefore, be classed into more than one movement category. Such phenomena are considered *multi-type* and, while generally uncommon, are possible when different spatial and/or temporal perspectives can be used to interpret a particular geographic subject matter. One such multi-type phenomenon involves travel, such as a plane trip. Spatially, a plane trip may be viewed as a point activity where only the origin and destination are of significance. The trip may also be interpreted as a linear phenomenon, in which case the route of travel is of importance. Different interpretations of a plane trip also occur in the temporal dimension. The trip may be viewed as an intermittent phenomenon for many passengers; the event is an unusual or highly irregular occurrence. The same trip using a different perspective may be considered a cyclical phenomenon; travel on the route is performed in a highly regular fashion during similar times of day and on similar days of the week. Yet other perspectives might focus on the actual trip itself and would consider the trip to be a continuous phenomenon from beginning to end. Any combination of each of these spatial and temporal perspectives of a plane trip will yield fundamentally different interpretations of the event. These varying

viewpoints in analysis are often distinguished by the names associated with the geographic phenomenon. For example, analysis of the individuals' changes in spatial locations is often referred to *recurrent human mobility* (e.g., movements of the pilots) and/or *irregular human mobility* (e.g., movements of the passengers). Spatial analyses of the periodicity of the path or travel route of the trip are often interpreted as *mass transit, regular* or *specialized route services,* as well as some forms of *trade and commerce.*

As the temporal and/or spatial scales of geographical analysis move from micro scales up through mega scales, the questions posed and views of interpretation may shift to yield the most appropriate perspective of the subject matter under investigation. Often times, such shifts of scale of analysis will lead to major shifts in the line of inquiry whereby different branches of science will examine the same subject matter. Studying tornadoes using subatomic levels will reveal entirely different information about the subject matter and would be investigated not by geographers, but perhaps by particle physicists. If interest in a plane trip concentrated on the changing coordinates in three-dimensional air space the plane travels through, the analysis may be performed by air traffic control. If interest in the movement of the plane focused on the plane itself (e.g., the internal combustion of the engine), the phenomenon may be studied by mechanical engineers. Studying the individual movements of the people as they travel through air space might be analyzed by a psychologist or behaviorist, while a physiologist might analyze the effects of air pressure on the movement of cells within the human body.

As demonstrated with tornadoes and plane travel, virtually any activity can be dissected and/or expanded, extending from the microscopic to the all-encompassing universe and beyond, using a wide array of temporal and spatial perspectives. For the purposes of this dissertation, only those spatially dynamic phenomena of general interest to the *geographer* are examined and classed as geographic movement. Geographers typically interpret, analyze, and describe dimensionally complex phenomena using systematic spatial and temporal contexts. Gross deviations from these traditional levels

of analyses will usually yield phenomena that are no longer of interest to the geographer but are to other scientists. While most geographic phenomena can be interpreted as a particular movement category, multi-type phenomena such as trips, which may be viewed with different spatial and temporal perspectives, are exceptions and therefore can be classed into two or more different movement categories.



Class 1 Continuous Point Movements

Continuous point movements occur when an object or phenomenon, as a point in space, moves uninterrupted through time. The spatial form this type of movement takes is point-to-point motion. With this category of movement, only the individual points or locales in space (i.e., its origins and destinations) are of significance as the phenomenon travels continuously through time. Routes or paths traveled are not so important as where the object is in space as it moves.

Global Positioning System (GPS) technology, which allows highly precise identification of an object's geographic location on the earth's surface, is often linked to continuous point movements in geographic space. *Vehicle navigation* and the *monitored individual movements* of a vehicle, animal, or person are activities that utilize GPS to record an object's different spatial locations as it moves across an area and are considered continuous point movements (Figure 4.2). With *vehicle navigation*, a driver can view the vehicle's location, as well as associated geographic features and landmarks such as highways and buildings, on a map display screen mounted on the dashboard. Such geographic information serves as a navigational guide in reaching the intended destination. In-vehicle navigation systems show real-time movement of the vehicle; the position of the vehicle while it is moving relative to the area around it is displayed with virtually no delay. Another application of GPS technology in the transportation industry is the

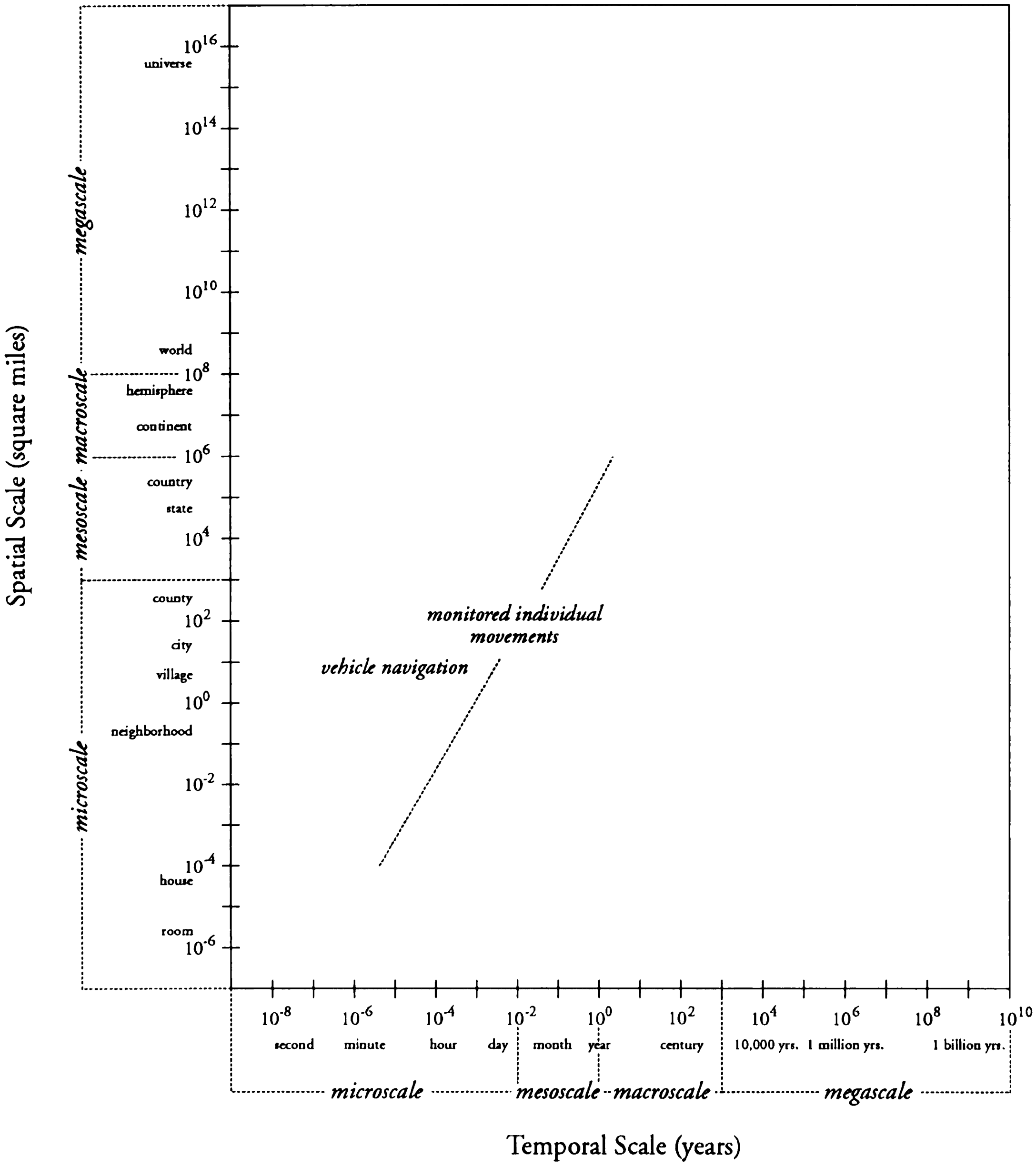
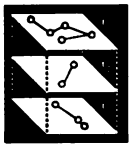


Figure 4.2 Scale Paradigm of Continuous Point Movements.

monitored individual movements of a vehicle where a vehicle's location is observed and sometimes directed from a central dispatch location (Jordan 1996). Emergency vehicle services and taxi companies, such as Yellow Cab in Denver, are beginning to integrate GPS technology not only as a way of optimizing dispatch by automatically assigning each call to the nearest available vehicle based on pickup and destination locations, but also as a way of monitoring the movements of its fleet drivers by displaying real-time locations of the vehicles (*Business Geographics* 1996). Both vehicle navigation and monitoring activities are microscale geographic movements which take place in minutes and hours within the confines of a town or city.

The *monitored individual movements of wildlife* and *people* are also considered continuous point movements and are possible with GPS as well as other wireless communications such as cellular telephone, radar, and radio waves. As with the use of radio collars, GPS technology allows the individual movements of endangered or otherwise tagged wildlife to be closely monitored for such purposes as habitat management. Law enforcement officials, who also use portable tracking devices that interface with global positioning system satellites and a cellular phone network, continuously oversee the movements and whereabouts of offenders, stalkers, and other criminals (*Business Geographics* 1996). At-risk medical patients, including Alzheimer's sufferers, can also be observed with wireless receivers. Monitored individual movements of persons and wildlife generally occurs in the micro to meso scale frames, both temporally and spatially. As GPS and other wireless communication technology allow for more advanced and prevalent monitoring, navigating, and automatic location capabilities in society, a greater understanding of how objects and individuals move continuously through space may be gained.



Class 2 Cyclical Point Movements

Cyclical point movements are those in which a phenomenon moves from point to point with a cyclical or predictable frequency. With this category of geographic movement, the importance of the phenomenon is the identification of the *linkages* or interaction between two or more points or nodes in space (i.e., locations). Many *wildlife migrations,* including those exhibited by salmon and Canadian geese, are regular seasonal movements and are considered cyclical point phenomena at meso to macro scales (Figure 4.3). One such phenomenon, the annual swallow migration to the Mission San Juan Capistrano, is a good example of how highly cyclical wildlife migratory movements can be. Every year around March 19 thousands of swallows migrate to the same exact location in southern California. The individual paths of the birds' migration are not the primary focus of examination; rather the unusual temporal aspect and spatial linkages of the movement are the key to understanding this unique activity. An important element in the explanation is the spatial and temporal *precision* of the *repetition* of the event, not the individual events themselves.

Most types of *recurrent human mobility* are also examples of cyclical point phenomena and include the movements associated with personal action spaces, urban homelessness, itinerant workers, journey-to-work, multiple residences, and human migration patterns. Borrowing from Gould and Prothero's (1973) distinction between mobility, migration, and circulation as they relate to human movements in tropical Africa, 'mobility' is understood to broadly include all population movements. Traditionally migration, as a population movement, has been defined as a *permanent* change in the usual place of residence between two points in time (Lowe and Moryadas 1975). The phenomenon of human migration has usually been conceptualized in terms of distance, gender, age, marital status, unemployment, and education using "standard tools"

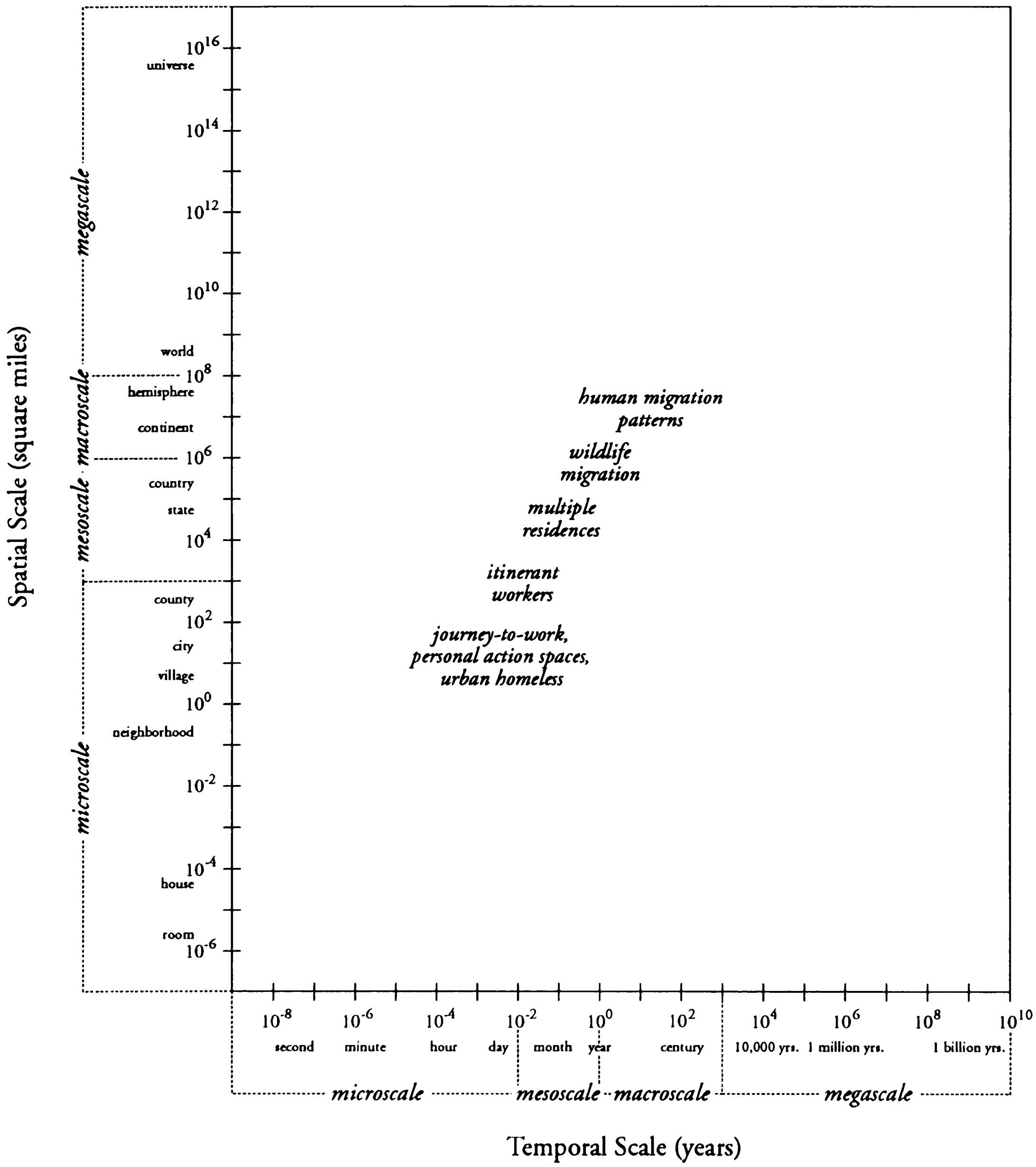


Figure 4.3 Scale Paradigm of Cyclical Point Movements.

such as 'life-cycle' theory, which implies a predetermined set of stages through which all individuals pass (Vandsemb 1995; Mitchneck and Plane 1995, 18). However, it has become increasingly evident that many people are exhibiting increasingly diverse histories such as schooling, cohabitation and living arrangements, marriage, child bearing, separation, divorce, remarriage, employment and career changes, etc. (McHugh, Hogan, and Happel 1995); thus, the notion of 'life-course' has replaced 'life-cycle' in recognition that not all individuals follow the same normative sequence of stages. Individuals are living and spending time in more than one place, moving between locales on a recurrent basis.

Therefore, migration is increasingly being defined as a *relatively permanent* change of usual residence. This definition seeks to differentiate migration from other forms of less permanent mobility that do not involve a change in usual residence, such as commuting and local trips, temporary employment elsewhere, and leisure travel (McHugh, Hogan and Happel 1995). Lowe and Moryadas (1975) operationalize this temporal component of migration by classifying the movement of persons as being temporary, transient, or permanent. For the purposes of this research, human mobility is considered to include *relatively permanent* or *less permanent* human movements. Relatively permanent movements involve one-way moves, where there is no intention of returning to the home base and are usually quite infrequent in nature. Individual residential migrations are good examples of these types of irregular movements and are discussed further as intermittent point movements. Less permanent mobility, which includes all temporary and transient moves where there is no change in usual residence, includes many types of recurrent human mobility which are considered cyclical point phenomena.

Roseman (1971) defines recurrent mobility as reciprocal movement, a morphological classification of human movement. Reciprocal movements are usually considered circulatory; individuals begin at the home or dwelling, proceed to one or more specific locations, and eventually return back to the home. Often, these repetitive human movements are subdivided according to the length of their cycles: daily, weekly, monthly, periodic, and seasonal (Gould and Prothero 1973; Roseman 1971). Microscale frequencies such as daily, weekly, or monthly movements of individuals are considered temporary and include consumers shopping for goods and services. Often this highly cyclical human movement is explained in a geographical context with the concept of 'action space.' Lowe and Moryadas (1975, 139) define action space as "the area which contains the majority of destinations of a particular individual... [and] is a subspace within the mental map." *Personal action spaces* occur at micro spatial and temporal scales, especially in automobile-oriented societies such as the United States, because most of the movement involves personal trips that can be satisfied in short distances and because of the need to return daily to home base. Numerous impediments are major determinants of the physical dimensions of action spaces and may include capability, coupling, authority, time, and budgetary constraints (Adams 1995). Individuals presumably try to maximize their return on the expenditure of time by adjusting their movement patterns and action spaces appropriately.

The mobility patterns of the *urban homeless*, namely where and how often homeless individuals travel within a city, also exhibit cyclical patterns of movement at the micro levels in both space and time. In studying intraurban mobility among the urban homeless in the Skid Row area of Los Angeles, Wolch, Rahimian, and Koegel (1993) assert that daily mobility patterns of homeless persons are subject to severe time-space constraints of almost every type and that movement is linked to degree of coping success. Coping, in turn, is tied to homeless social connections, the availability of urban resources, and broader contextual factors that shape access to Welfare benefits, jobs, housing, and other critical human services. Wolch, Rahimian, and Koegel (1993, 163) suggest that homeless people are extremely mobile within a portion of an urban area and that their daily movements are highly cyclical: "Thus, most people do similar things every day and meet the same people at various junctures throughout the day. They often start and end their day in the same spot." The authors also suggest cyclical behavior of the homeless in terms of intraregional mobility, where many homeless persons have a weekly, biweekly, or monthly routine of longer trips within the greater metropolitan region.

Another type of cyclical human mobility occurring on a daily basis is the *journey-to-work*. Geographers have long studied workers' mobility patterns in terms of the influence of variables such as gender, household responsibilities, central city versus suburban residences, and travel mode on trip lengths, measured either by distance or travel time (Johnston-Anumonwo 1992). The time-space structure of this recurrent human mobility phenomenon is conceptualized at a micro scale, both temporally and spatially. Occurring at slightly larger scales are the cyclical movements of many *itinerant workers* whose jobs take them from place to place. Workers such as traveling salespersons, agricultural laborers, professional athletes, miners, and construction and oilfield workers travel with varying periodicities and usually return repeatedly to a 'home' base (McHugh, Hogan, and Happel 1995). For example, pastoralists move seasonally; their daily rhythm is similar to that of nomads, but whose movements have an overall discernible, annual regularity in space and time (Gould and Prothero 1973). In the United States, agricultural labor moves seasonally from the Mexican border northward along the West and East Coasts as well as the Great Plains, following planting and harvesting demands.

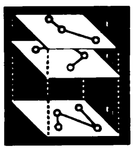
Once initiated, cyclical mobility may persist for spells ranging from weeks and months to many years (McHugh, Hogan, and Happel 1995). Recurrent circulatory human movements of such large temporal scales (meso to macro) are those of individuals with *multiple residences*. Described as 'transient movers' (Lowe and Moryadas 1975), individuals with more than one residence often exhibit a very orderly pattern of movement between two points in space that can range from weekly or monthly circulation between residences during a life-course phase (e.g., children shuttled between divorced or separated parents, students who return home during semester breaks and summers, or military reassignments) (McHugh, Hogan, and Happel 1995), to weekly circulation between

residences across the life-span (e.g., family second homes) (Behr and Gober 1982), to what Roseman (1992, 38) describes as biannual treks between summer and winter residences over a lifetime (i.e., elderly "snowbirds"). 'Snowbirds,' who are often stereotyped as healthy, active couples pursuing leisure-related lifestyles in their early retirement years and living a sort of "footloose lifestyle," are, as McHugh and Mings (1996, 539) suggest, highly cyclical transient movers: "Once established, cycling between summer and winter places takes on a 'matter-of-fact' quality, it becomes part of an annual space-time routine."

A final form of human mobility that is considered a cyclical point phenomenon are some ***human migration patterns.*** Using a macroscale reference for both the spatial and temporal dimensions, some human migration patterns when observed over lengthy time periods and across large expanses of space are quite cyclical in nature. In studying long-term global migration patterns, Berry (1993, 389) suggests that transnational urbanward immigration flows have fluctuated with a "cyclical, pulsating... long-wave rhythmicity" that mirrors the movement of successive techno-economic systems from innovation to market saturation.

Regardless of the duration or spatial extent of the movement, several forms of human mobility can be viewed as cyclical, point-to-point movements and include large scale migration patterns, as well as individual movements associated with personal action spaces, homelessness, journey-to-work, itinerant workers, and multiple residences. Recurrent cyclical mobility involves oscillatory movements which vary in tempo and duration and range from frequent back-and-forth movement over a brief period (temporary job assignment) to biannual treks between summer and winter residences over a life-course phase (snowbirds) to circulation between residences across the lifespan (family second homes) (McHugh, Hogan, and Happel 1995). McHugh and Mings (1996, 538) describe such tempos and rhythms associated with geographical mobility as "place ballet on a grand scale" where "elegance and grace" exist in the "recurring cycle of separation and return." With this movement category, the geographic importance of the phenomenon's

movement are the beginning and ending locations of two or more points in space, the occurrence of which is cyclical over time.



Class 3 Intermittent Point Movements

The third type of geographic point movement is intermittent in its temporal character. With this category of movement, an object or phenomenon moves infrequently from location to location, without regular intervals. As with all point-to-point movements, the spatial emphasis is on the from-to linkages of the two or more locations in space. Examples of this movement class include forms of *irregular human mobility*, including movements associated with residential migration, immigration, refugee and nomadic behavior, leisure travel, and personal action space, as well as volcanic and seismic activity (Figure 4.4). *Residential migration*, defined as "a permanent or semi-permanent change of residence, usually across some type of administrative boundary" (Wood 1994, 607), can be described spatially as a point-to-point move: "the geographic area that sends major migration flows to a given *place* (i.e., a city, metropolitan area, or county), or the area that receives major flows from a *place*... in effect, that place is treated as a point in space" (Jakle, Brunn, and Roseman 1976, 165-166). Whereas many forms of human mobility are repeated frequently, often at regular intervals (see discussion of class 2, cyclical point movements), individual residential migrations are less frequent and tend to be related to such episodic events as graduation, marriage, and retirement. Such irregular human displacements, where the center of gravity of the weekly movement cycle, the home, moves to a new location, are essentially one-way and are considered relatively permanent given that further movement is likely in the future, but neither the time nor the direction of such movements are known.

Understanding the irregular patterns of residential migrations of individuals requires

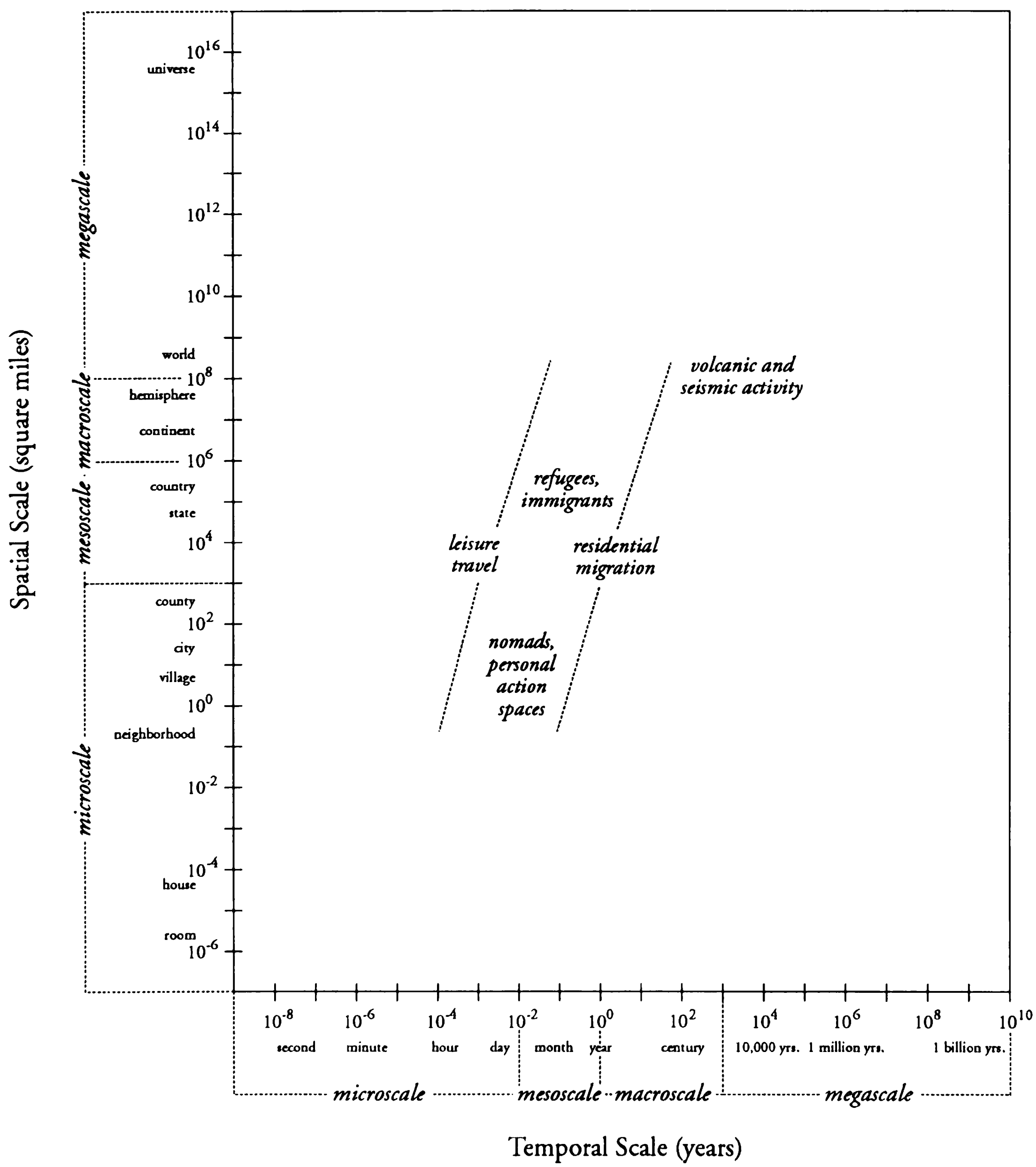


Figure 4.4 Scale Paradigm of Intermittent Point Movements.

a meso to macro temporal scale and a spatial scale varying from micro to mega; an individual's residential moves over a life time may be numerous yet sporadic and can occur within a same town or city or can extend to the far corners of the world. Understanding the irregular patterns of residential migrations of aggregates of individuals is equally as complex. The current interstate migration system in the United States oscillates between relatively brief periods of abrupt systematic change in established migration patterns followed by longer periods during which new migration equilibria are established. For example, migration patterns in the early 1980s were different from those in the mid 1980s, which in turn bore little resemblance to migration in the early 1990s. Manson and Groop (1996, 156, 165) describe this phenomenon as "temporally and spatially transitory" and argue that "it is neither feasible nor necessary to impose a spatial generalization on such a dynamic system."

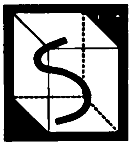
The behavior of *immigrants*, *refugees* and *nomads* also may exhibit sporadic and irregular movements (Gould and Prothero 1973). Many quantitative studies attempt to explain the socioeconomic causes and consequences of such migrations, especially at meso to macro scales, by describing the sort of societies that are ejecting or attracting certain types of migrants. Political considerations both encourage and inhibit the movement of people; most countries have stringent regulations about who may enter (Lowe and Moryadas 1975). In examining the undocumented (illegal) Mexican migration to the United States, immigration has fluctuated with economic cycles in the States during the first four decades of the twentieth century, going from stages of active recruitment to periods of forced repatriation. In recent times, step migration has come to play a major role in the flow of undocumented migrants traveling great distances to reach their destinations in areas in the southwest of the United States. Step migration occurs through intermediary locations called "redistributive cities" (e.g., Nogales, San Luis, Tijuana) that serve as "jumping-off-points," tying internal and international migration (Harner 1995, 399).

Migrant population patterns are also affected during political and economic tensions, especially during armed conflict (Mitchneck and Plane 1995). Refugees, individuals who are forced by a well-founded fear of persecution to migrate involuntarily across an international boundary (Bascom 1993), may migrate many times, for varied durations, and across numerous territorial divisions (Wood 1994). Such is the case with Ethiopia, where the largest and longest forced mass movement from one country in postcolonial Africa has taken place. Beginning in 1967 when 30,000 Ethiopians fled from the northern province of Eritea into eastern Sudan, the combined "Ethiopian Diaspora" now includes more than one million people, the majority of whom are sheltered in the neighboring countries of Somalia, Djibouti, and Sudan (Bascom 1993, 320). Interpreting the migratory moves of nomads requires micro and meso scale references; migration is not dependent on a cyclical or predetermined frequency, but rather moves occur according to the day-to-day availability of pasture and water for their animals. Where and when their next move may not be precisely known.

Other forms of irregular human mobility include temporary movements associated with periodic and intermittent activities outside the home. Such movements can range substantially in scale, both spatially and temporally. Vacations and visits to family or friends are all *leisure travel* activities associated with irregular human mobility and can include hourly visits to locations within one's neighborhood to vacations lasting several weeks or more in areas as far away as across the world. Some types of individual movements associated with one's *personal action space* may also be considered intermittent point movements. Although many individual activities at micro spatial and temporal scales are highly regimented, as discussed in class 2, cyclical point movements, periodically one may travel to different points within one's action space for the purpose of satisfying some infrequent need for goods or services. Human movements are purposive to a degree; an individual has either knowledge or the willingness and ability to search space to find out the distribution of available opportunities for various purposes. Such is the case

with intermittent human movements associated with patient health care access. Often in rural outlying areas, people will travel great distances and cross administrative boundaries to receive specialized health care. The dominant characteristics of this irregular human movement is that it occurs between rural and urban counties and on an infrequent basis in mesoscale time (Lowe and Moryadas 1975).

Other examples of intermittent point movement include *volcanic* and *seismic activity*. Whereas a particular volcanic eruption or earthquake is a continuous volumetric movement and eruptions from the same volcano or earthquakes occurring along the same fault line are be described as volumetric movement (see discussions of volumetric movement classes 10 and 12, continuous and intermittent, respectively), volcanism, a general term for volcano building and related forms of extrusive igneous activity, and seismic activity are both phenomena that, when examined at very large spatial and temporal scales, are considered to be intermittent point movements. Viewing the entire world as one giant activity space over thousands to millions of years, individual eruptions and earthquakes, when observed in relation to one another, can be described as 'hot spots' jumping from one point to another intermittently. Nearly seventy-five percent of the world's approximate 540 historically active volcanoes lie within the "Ring of Fire," a zone running along the western coast of the Americas from Chile to Alaska, down the eastern coast of Asia from Siberia to New Guinea, and continuing to New Zealand (Famighetti 1996, 588). Here, active volcanoes can erupt repeatedly over a period of thousands of years, the frequency and occurrence of which are unpredictable. Earthquakes occur intermittently and at scattered but relatively similar locations throughout and beyond the circum-Pacific belt. During the course of the last century or more, over 120 major earthquakes have occurred throughout the world, the frequency and relative location varying significantly (Famighetti 1996).



Class 4 Continuous Linear Movements

Continuous linear movements are those associated with an entity that is continuously changing its spatial location along a path. The geometric shape of the movement as it travels through space and time is an unbroken line; the linear form representing some pathway, channel, or route. The temporal aspect is uninterrupted, representing movement that is continuous, from beginning to end. Of general interest to the geographer, this linear kind of movement which occurs among specific origins and destinations is often described as the 'flow' between locales. A spatial flow is "an observable phenomenon which can be measured directly as the specific volume passing a point during a particular time interval" (Lowe and Moryadas 1975, 158-159). Flows in human and physical systems are a focus of geographic inquiry because "they involve movement across space that connect origins and destinations and because they redistribute water, sediment, energy, population, products, and economic activity" (Graf and Gober 1992, 239). What is significant about this class of movement is the movement of the path itself; movements occurring *within* the path or track are examined as other spatial forms that are more important to the understanding of the phenomenon then its linear motion (e.g., with a flood, the important issue to note is not the expanding borders of the river channel but the depth or *volume* of the channel). Geographic phenomena classified in this movement category travel continuously across space in a linear fashion and include forms of *electronic communication*, *jet streams and water channels*, *hurricanes*, *tornadoes*, and the *revolution of the earth* about the sun (Figure 4.5).

The electronic transmission of information, hereafter referred to as *electronic communication*, is considered to be a continuous linear movement. Utilizing wire systems such as telephones, computers, and televisions, electronic communication involves the spatial interaction between two or more places conducted through highly concentrated

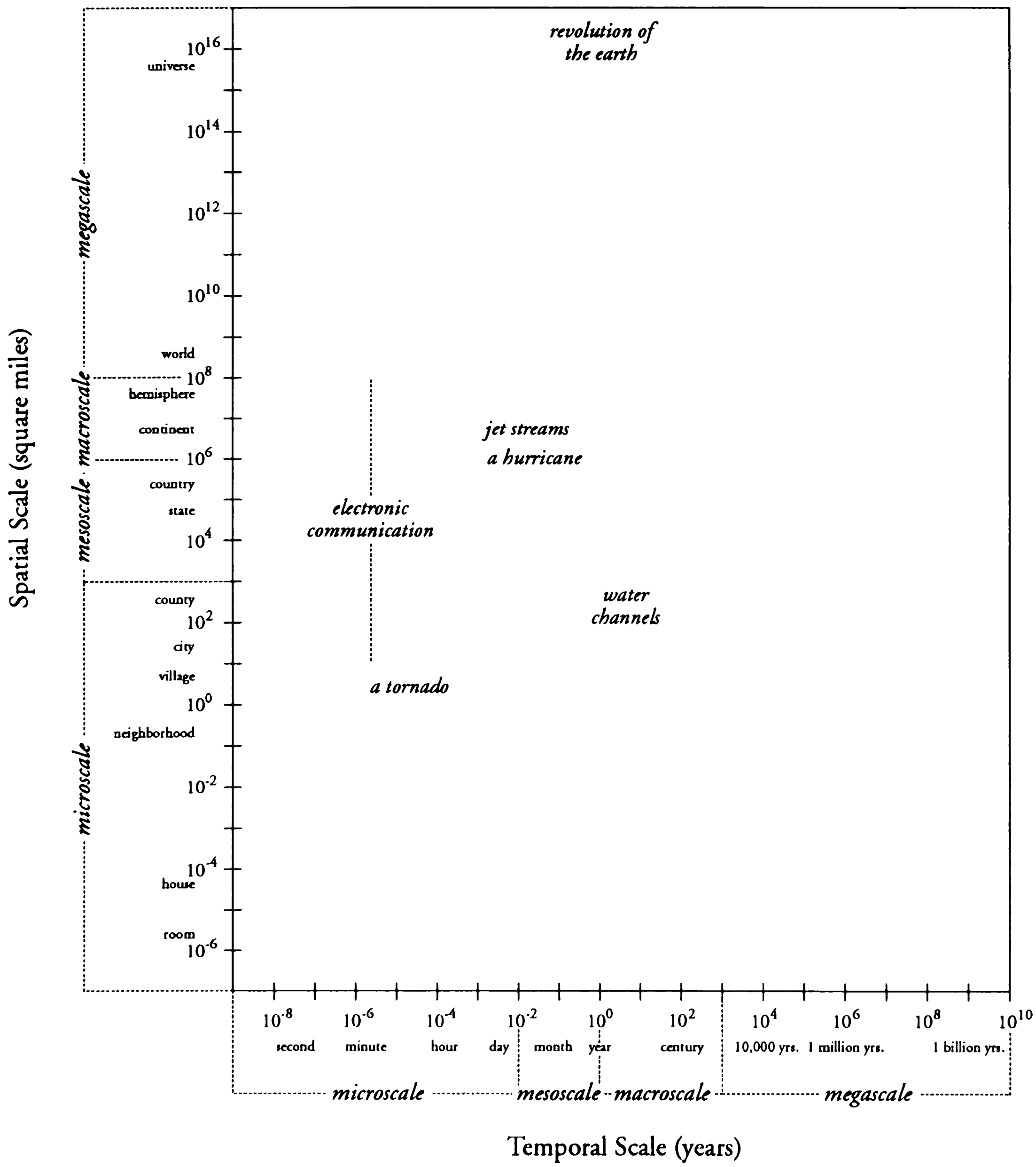


Figure 4.5 Scale Paradigm of Continuous Linear Movements.

channels, especially with regard to information flows (Mitchelson and Wheeler 1994). Once a signal is sent, movement of information is continuous, traveling along an electronic pathway until the connection is broken. Adapting from the Shannon/Weaver mathematical theory of communication, Jakle, Brunn, and Roseman (1976, 121-122) describe electronic information transmittal as "bits of information emanating from a source, sent through some transmitting mechanism such as a voice, printing press, or radio, then through a channel of some sort, and finally on to a receiver at a given destination." The exchange of information using electronic wire communication systems generally occurs within seconds and minutes (micro time frames), but varies considerably in spatial scale, ranging from local to world-wide connections and links.

Another example of a constant linear phenomenon is the *revolution of the earth* about the sun. Simultaneously with rotation on its axis, the earth is in continuous motion in an orbit around the sun. The geographic view typically used in the description and explanation of the revolution of the earth describes earth as one of many objects or points in space that move constantly and steadily in elliptical patterns with respect to the sun. Spatially, this phenomenon is interpreted on a megascale, where the spatial extent of the movement occurs within a galaxy. The earth completes its orbit in one year and falls within the mesoscale temporal domain. This period of the earth's revolution is important as it sets the timing for climatic seasons.

Jet streams and *water channels* are also geographic phenomena that move in a continuous linear fashion. Jet streams are narrow bands of high velocity winds in the upper level troposphere that follow the wave path near the tropopause at elevations of eight to fifteen kilometers (Critchfield 1983). This phenomenon consists of pulselike movements of air following broadly curving tracks; a cross section of the jet resembles a stream of water moving through a hose (Strahler and Strahler 1984). As part of the earth's dynamic atmosphere (see class 10, continuous volumetric movements), jet streams are continuous phenomena. Frequently shown on television and other animated weather displays as a

dynamic line snaking its way across the earth, the concept of a jet stream is best understood using a macro spatial scale and a meso temporal scale, with which areas such as the continental United States are viewed over the course of several days. Water channels such as streams, creeks, and rivers are also considered continuous linear phenomena. Analogous to jet streams, water channels are comprised of continuous volumetric movement but whose changing boundaries are often significant. Streams and rivers are constantly changing their path (i.e., 'meandering') and are best interpreted at micro to meso spatial scales over the course of several months to years.

Additional examples of geographic phenomena included in this movement category are individual occurrences of some types of severe cyclonic storms such as a *hurricane* or a *tornado*. Traveling cyclones, atmospheric circulations of winds rotating counterclockwise in the northern hemisphere and clockwise in the southern hemisphere (Famighetti 1996), are centers of low atmospheric pressure that produce cloudiness and precipitation due to the convergence of air masses toward the cyclone centers accompanied by lifting of air and subsequent adiabatic cooling (Critchfield 1983). Dependent for their development on the coming together of large air masses of contrasting properties, cyclones are typically mild in intensity, passing with little more than a period of cloud cover and light rain or snow. However, when pressure gradients are strong and accompanied winds reach gale force, the disturbance is called a cyclonic storm. As an intense cyclonic vortex of enormously powerful winds, or as a tropical cyclone of tropical and subtropical ocean areas, a tornado and a hurricane, respectively, are best understood *geographically* as continuous linear movements.

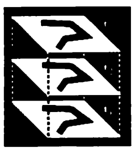
When these two types of severe cyclonic storms occur, they are part of the earth's atmosphere and, meteorologically speaking, are volumetrically dynamic phenomena at very micro scales (i.e., tremendous volumetric rotation of the air at or near the center of these cyclones). At larger micro spatial and temporal scales, individual occurrences of each of these phenomena could also be considered objects or points in space given the exact

locations these entities are coming in contact with the landscape changing with each new time frame. However, geographic focus on these phenomena generally employs larger frameworks. Geographers typically evaluate the relationship between a particular storm and the landscape with which it is interacting (i.e., the *path* a disturbance is traveling) for the major purpose of improving forecasting and emergency management operations.

Using moderate scale frames, a hurricane falls within the meso temporal scale as, from creation to dissipation, it can travel for several weeks. Spatially, the movement of a hurricane is best understood using meso to macro scale references, where storms can cover tens of degrees of both latitude and longitude (Strahler and Strahler 1984). Once formed, a hurricane typically advances fifteen to thirty kilometers per hour westward through the trade-wind belt, at which point it may then curve north and northeast where it penetrates well into the belt of westerlies (Strahler and Strahler 1984). The area of hurricane force winds (seventy-three miles per hour or higher) takes the form of a circle or an oval, sometimes as wide as 300 miles in diameter (Famighetti 1996). The National Weather Service's National Hurricane Center (NHC) tracks, among other characteristics, a storm's movement or travel path. By making specific forecasts of landfall points and times, the NHC can aid emergency management officials with advisories and evacuation orders (Baker 1995).

A tornado's movement needs micro temporal and spatial scales to be examined. Tornado paths can vary in length from a few feet to nearly 300 miles (average is five miles) and in diameter from a few feet to more than three to five kilometers (average is 660 feet) (Famighetti 1996; Critchfield 1983). As a tornado moves across the landscape, its rate of travel at the ground averages thirty miles per hour but may reach fifty knots or more and may remain relatively stationary for short periods. Some contact the ground and then lift, only to strike again at a distance of several kilometers; still others may travel only a few meters before rising and dissipating (Critchfield 1983). Regardless of its actions, geographically a tornado, as with a hurricane, is examined chiefly for its

location and subsequent travel path. Locating the important regions of cyclogenesis and the general tracks taken by these cyclones as a way of understanding the spatial and temporal *trends* of tornadoes and hurricanes is also of geographic concern (Raphael and Mills 1996) and is discussed next in class 5, cyclical linear movements.



Class 5 Cyclical Linear Movements

Cyclical linear movements are those in which a phenomenon repeatedly moves across the landscape in a linear or path-like fashion, and does so with a predictable frequency. The key to understanding phenomena classified as cyclical linear activities is to visualize a subject or object moving across the surface of the earth along pathways and routes in a systematic and regular pattern. *Hurricane and tornadic activity,* as well as activities that utilize transportation networks of various scales for the scheduled movement of people, goods, and services such as *mass transit* and *regular route services, trade, and commerce*, are examples of geographic phenomena that move along linear paths across the landscape in regular frequencies (Figure 4.6).

Viewed at meso to macro temporal and spatial scales, *hurricane* and *tornadic activity* are considered cyclical linear phenomena as both exhibit fairly predictable temporal, as well as spatial, patterns of behavior. Occurrences of both types of cyclonic storms are cyclical phenomena in that they are seasonal activities; hurricane season generally extends from June to September in a given year while tornadoes are most frequent in spring and summer months. Equally regular are the spatial characteristics of these storms. Hurricanes only occur in tropical and subtropical zones on earth, form over warm water, and travel in a westerly then northwesterly fashion, while the tornado is a typically American phenomenon occurring primarily in the southern High Plains of the United States (Strahler and Strahler 1984). In studying selected temporal and spatial

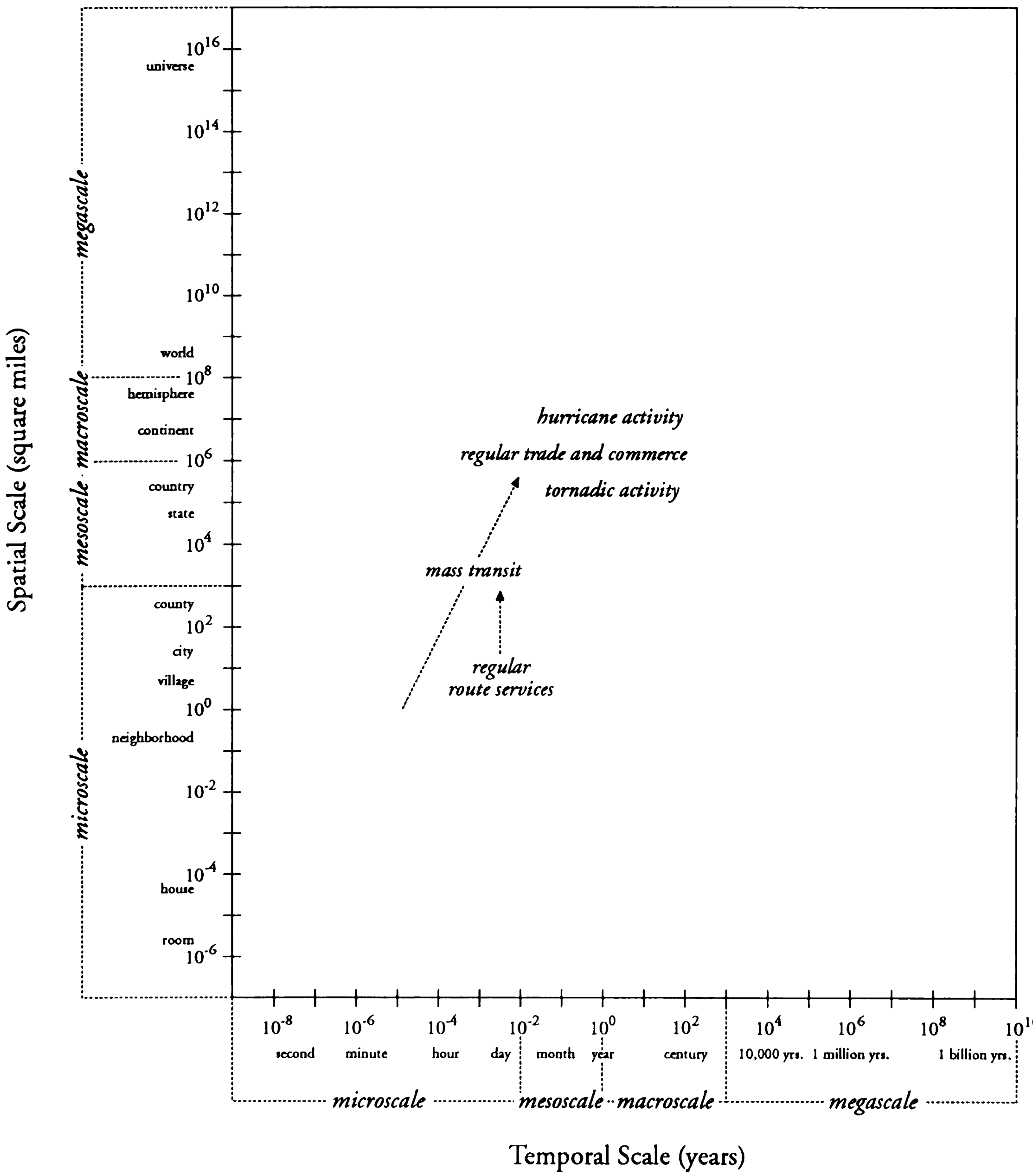


Figure 4.6 Scale Paradigm of Cyclical Linear Movements.

characteristics of Michigan tornadoes over a fifty year period, Stolle (1987) concludes that tornadoes in the region do not occur at random times or location, but that this phenomenon generally occurs during late afternoon to early evening hours most predominately in the spring months of April, May, and June and moves fairly consistently in a north to northeast direction.

Movement associated with most forms of transportation can also be classified in this category. Transportation involves the physical movement of people, goods, or services, between two or more places and can take place with a series of different transportation modes (e.g., auto, train, bus, airplane, boat, etc.) in a network. In adapting graph theory to transportation, essentially the topological structure of a route network is a set of geographic locations (nodes or points) interconnected in a system by a number of routes (links) (Haggett and Chorley 1969). Movement originates and ends at nodes, and flows occur on route networks (Lowe and Moryadas 1975). How well a node such as an urban center or airport is connected to other nodes is described by connectivity (Lee, Chen, and Shaw 1994). Connectivity measures "linkage intensity;" the higher the number of routes or paths connecting two or more points, the greater the linkage intensity and, therefore, the closer the network comes to a maximally connected structure (Ivy 1995, 283). Network route structures (i.e., the way that links are connected with each other) (Lee, Chen, and Shaw 1994) act as the arterial and nervous system of regional organization (Haggett 1979, 490) and are made up of many links of various size which are hierarchical. This branching structure, analogous to river systems, contains a few heavily used channels and many highly used feeders, or tributary channels (Lowe and Moryadas 1975; Haggett 1979).

The evolution of transportation networks occurs not only at the macro spatial scale of nations and large regions, but also at the micro scale of urban areas. Perceived and analyzed as linear forms on the human landscape, transportation is a phenomenon in which people and cargo are carried from one location to others along designated routes or links. These linkages or paths are typically highway, railway, airway, and/or waterway networks that weave across the landscape. Major transportation routes are sometimes referred to as 'arteries,' where a transportation system keeps a complex space-economy functioning (Lowe and Moryadas 1975). Impediments and disruptions to established networks such as accidents, construction, and inclement weather conditions can have paralytic effects and may alter a chosen route. Route reallocation is perhaps the easiest to accomplish with air transportation networks. Unlike largely fixed overland infrastructure links such as railroads, canals, and highways, airline routes can, with governmental approval, be added or deleted at will (Ivy 1995). Despite such disruptions to a particular transportation activity, the *form* of the transporting of people, goods and services as a linear movement remains unchanged.

Mass transit, as a public transportation phenomenon, is a cyclical geographic movement largely because the activity occurs rather predictably; the times the transport begins and ends is similar and predetermined with most occurrences. Each mode of transit has fixed schedules and carriers within each transportation network travel in systematic and regular frequencies, which are usually unique in terms of their network structure. For example, the flight frequencies of various routes in an airline's network depend on the demand and desired service levels, the types of aircraft used, and the degree of competition from other airlines between different pairs of cities (Lee, Chen, and Shaw 1994). The duration of a transit varies among carriers in this category, but is virtually identical for each frequency in a given mode within a transportation route. While delays and disruptions in service are commonplace to the frequent traveler, the movements associated with mass transit are generally cyclical events. Mass transit can occur over a wide range of temporal and spatial scales; movements of city buses across part of an urban landscape are measured in minutes, air and rail transit occurs within and across states and countries and is measured in minutes, hours, and days, and ship travel, which may occur over days and weeks, can cover areas as large as the world.

The argument could be made that at fine temporal scales, frequent stops along a mass

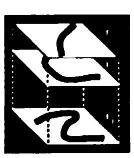
transit route represent point-to-point activities and that the movement associated with the transportation is discontinuous from beginning to end. This may be true at the most personal scale and is discussed as a form of recurrent human mobility in class 2, cyclical point movements. Geographically, interest in mass transit systems typically lies in the links between the nodes (i.e., the routes); the important considerations of mass transit routing is a service's relationship between time and space, and how this relates to efficient route planning including cost-benefit ratios and spatial allocation models.

Another cyclical geographic phenomenon that utilizes transportation networks is *regular route services.* Routes are channels along which interaction occurs between any two nodes or locations. "Interestablishment interactions" such as courier mail, commercial deliveries, many home care services such as Meals-on-Wheels, and waste disposal and recycling are examples of regular route services (Lowe and Moryadas 1975, 166). Such delivery and pick-up services can be seen as cyclical linear activities where information, products, and freight, such as mail, garbage, and commercial goods, are moved from production locations to consumption locations, all the while traveling along an established transportation route. These activities are largely cyclical in that services are typically rendered in a systematic and orderly time frame, usually incorporating highly frequent, but regimented schedules such as hourly, daily, and weekly patterns. Most regular route services occur across micro scales, both spatially and temporally. However, information, goods, and services exchanged on a regular schedule may be transported in more complex, spatially extensive patterns, such as Federal Express deliveries:

> "... packages were picked up and taken by van or truck to a specified nearby airport, placed on a Federal Express airplane, flown to the central sorting facility in Memphis, put back on the appropriate aircraft and flown to their destinations where they would be delivered the next morning."
>
> (Wheeler and Mitchelson 1989, 527)

Regular trade and commerce are also examples of cyclical linear geographic phenomena that utilize transportation networks. A fundamental cause of commodity

movement is the existence of spatially concentrated resources, such as corn in the Midwest, oil in the Persian Gulf, and coal in Appalachia which, in turn, leads to surplus and deficit areas. Each region exchanges its surplus for other surplus commodities produced in other specialized regions (Lowe and Moryadas 1975). Regional transportation infrastructure, especially air transportation, is the 'lifeline' for such economic interchange (Ivy 1995). The flow of capital and commercial and industrial goods across regional and international boundaries is best understood using meso to macro spatial scale references. The exchange of commodities often occurs in regular patterns measured in days, weeks, and even months and is primarily a mesoscale temporal phenomenon. Some cyclical commodities exhibit seasonal periodicities such as the shipment of strawberries in the summer and the mailing of Christmas cards in Mid-December (Lowe and Moryadas 1975). However, other kinds of trade and commerce are sometimes irregularly administered and are discussed further in class 6, intermittent linear movements.



Class 6 Intermittent Linear Movements

A third class of linear geographic movement is intermittent in its temporal frequency. Recapitulating from the discussion of cyclical linear movements, many geographic phenomena involving transportation are interpreted easily as linear movements that are considered purposeful; there is one location of supply and another of demand. Occasional home delivery services such as fast food, flowers, and furniture, as well as public services such as police, fire, and ambulance, represent *specialized route services* (Figure 4.7). With delivery of these kinds of goods and services, supplies move from one location to another based on need which is unpredictable and irregular in micro space and time. Supply and demand economics, which can fluctuate irregularly, govern when these movements occur and where their origins and destinations will be. This same principle

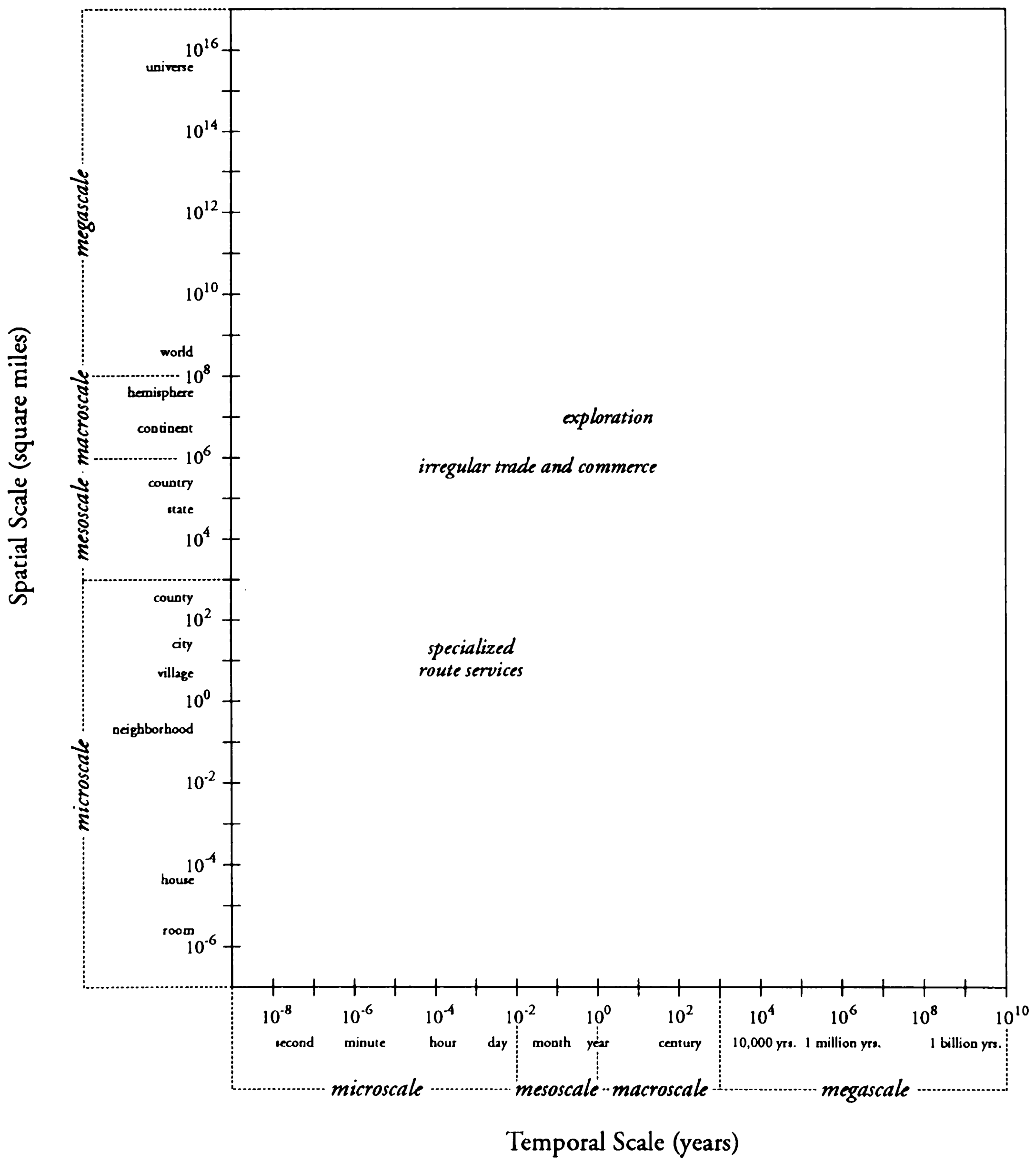
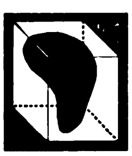


Figure 4.7 Scale Paradigm of Intermittent Linear Movements.

extends to some intra- and inter-regional *irregular commerce* and *trade.* Using meso to macro spatial and meso temporal scale references, many commercial goods and imports/exports can be seen to move from one locale to another via any number and combination of transportation networks, the frequency of which "do not usually experience periodicities" (Lowe and Moryadas 1975, 166).

Another example of intermittent linear geographic movement is the historical phenomenon of *exploration.* Voyages and expeditions of discovery and exploration, especially to the New World, were most prevalent during the fifteenth and sixteenth centuries. Such journeys are best understood with macro spatial and temporal scopes; voyages across oceans and along the coasts of continents often lasted several months to years. An exploration can be interpreted as a broken linear path extending from point to point to point as a ship would dock along the way at key ports for necessary supplies and reinforcements. Exploration, as an intermittent linear movement, is best understood as a phenomenon moving along a route or pathway from a point of origin to specific destinations, occasionally stopping for periods of time.



Class 7 Continuous Areal Movements

Continuous areal movements involve phenomena that spread out across the landscape in a radial fashion and do so continuously through time. Imagine a drop of dye spreading out or 'bleeding' on a piece of fabric; the movement is continuous throughout and when the spread stops, a contiguous area around the point of origin is affected. Exhibiting similar movement behavior is diffusion, the geographic spread of a phenomenon. The *diffusion of* human settlement (*colonization*), *innovation, culture, and disease*, as well as *acculturation and assimilation*, some forms of *regional boundary changes*, and *forest fires* are examples of continuous areal phenomena (Figure 4.8).

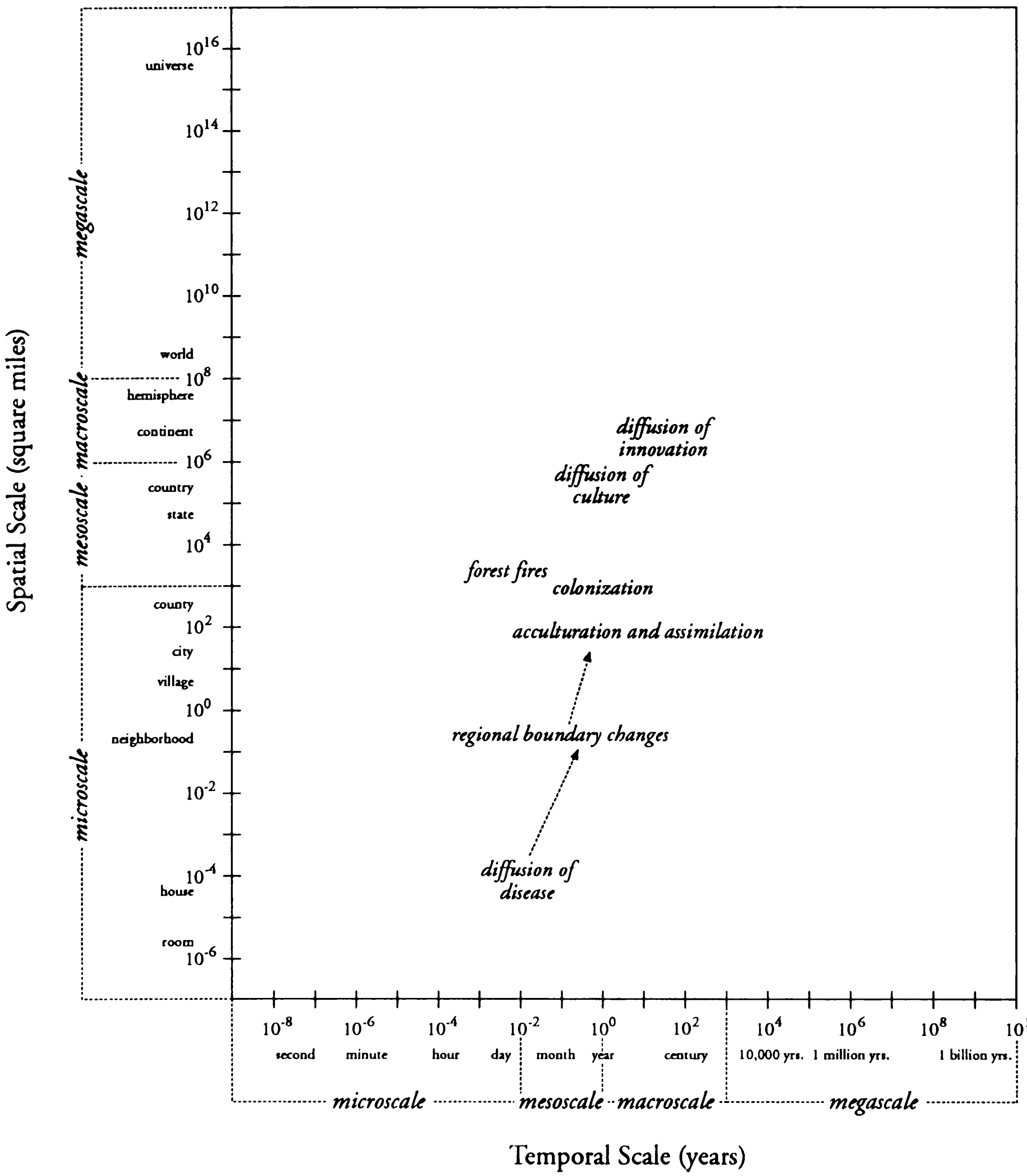


Figure 4.8 Scale Paradigm of Continuous Areal Movements.

Diffusion cannot be described in a static way (Jakle, Brunn, and Roseman 1976); rather "it is necessary to mesh space and time simultaneously, since the spread of an innovation over an area is neither geographically uniform nor temporally instantaneous" (Lowe and Moryadas 1975, 242-243). Spatial diffusion is an important form of place-to-place movement or spatial interaction; the term itself suggests movement, interaction, spread, contact, change, and growth (Hudson 1972). A principal concern of social geography, and geography in general, is the way in which new ideas, new inventions, and other traits and practices diffuse from individual to individual and group to group across the landscape (Jakle, Brunn, and Roseman 1976). Diffusion studies have a rich heritage in geography and can be traced back to the late 1800's and the German anthropo-geographer Ratzel who introduced the fundamental idea of something starting somewhere and spreading out like ripples on a pond (Lowe and Moryadas 1975). This conceptualization of diffusion refers to the 'wave-like' nature of the phenomenon: "In a true diffusion process, the loci of action are themselves expanding in space and time, rather like an impact wave, out from an origin, as from a rock dropped into the water (Morrill 1968, 2). This description of "waves flowing continuously over space" characterizes the growth process of diffusion, whereby items become relatively less concentrated over space but relatively more concentrated over time (Jakle, Brunn, and Roseman 1976, 144).

Parkes and Thrift (1980, 286) define this principle as "diffusion time," a term describing the slow acceptance of an idea, culture, etc. at the beginning of a diffusion process, which then accelerates until the frequency of acceptance is greatest (i.e., saturation) after which the rate of acceptance declines until no further acceptance occurs (Morrill 1968). The adopters themselves influence the way in which innovations and ideas spread through a population over time and may be classed into one of four categories, each dependent on decreasing individual rates of adoption, respectively: innovators, early adopters, late adopters, and laggards. These acceptance rates of adoption influence a diffusion wave, which has four distinct stages: a *primary stage* where centers of adoption are

established, a *diffusion stage* where the process begins and a powerful centrifugal effect results, a *condensing stage* where the relative increase in the number accepting is equal in all locations, and finally a *saturation stage* in which the slowing and eventual cessation of the process occurs.

Essentially two distinct types of diffusion prevail within the geographic discipline: *contagious diffusion* and *hierarchical diffusion*. *Contagious diffusion* depends on direct personal contacts and is strongly influenced by distance (Haggett 1979); near potential adopters receive an innovation before more distant ones (Lowe and Moryadas 1975). Expansion and relocation diffusion are kinds of contagious diffusion where information, materials, etc. are spread from one place to another and the spread is strongly influenced by neighborhood effects (Parkes and Thrift 1980). These two types of contagious diffusion differ in that with relocation diffusion, the things diffusing actually leave the area where they originated (e.g., African Americans relocating from rural south to northern cities) (Haggett 1979). *Hierarchical diffusion* involves transmission through a regular sequence of order, classes, or hierarchies. A common type of hierarchical diffusion is cascade diffusion, where processes are assumed to move downward, from large centers to smaller areas (Haggett 1979). Large places, important people, or powerful institutions tend to get word of new information or innovations first and then transmit this information, usually selectively, down the hierarchy of places, people, or institutions (Parkes and Thrift 1980). As a result, early adopters may be located at relatively great distances from the center of diffusion, while nearer potential adopters are temporarily bypassed (Lowe and Moryadas 1975).

Perhaps one of the first diffusion phenomena of geographic study was settlement patterns. *Colonization*, comprising a traditional part of human geography, formed such distinctive features on the landscape that they were viewed as "a fundamental expression on 'man-land' relationships" (Garner 1967, 303). Traditional emphasis was placed on form and patterns which were essentially viewed as a reflection of physical controls (i.e.,

mountains, rivers, etc.), supplemented heavily by historical influences. Beginning with the first Virginia expedition to Chesapeake Bay in 1607 and extending to the turn of the twentieth century, as more and more migrants came to America the movement of colonization expanded outward from central ports and activity hubs along the Atlantic seaboard from central Maine to the Carolinas, eventually expanded westward toward the Piedmont and Appalachian backcountry, and finally from the Great Plains to the West Coast during the drought in the 1930's (Roseman 1977). Between 1650 and 1675 alone, this settled region (areas with two persons or more per square mile) expanded at a rate of three percent per year. Colonization of places such as Jamestown, Boston, Philadelphia, New York, and Baltimore followed a modern urban system of settlement; "tiny nuclei grew overnight into palpable places" (Earle 1992, 484). Viewed at micro and meso spatial scales and meso and macro temporal scales, colonization can be regarded as a continuous areal movement where people move from various places to new, largely uninhabited locations, all the while settling areas in between.

With the spread of settlement across the landscape came the diffusion of innovation, culture, and disease. An innovation is a new idea or technology that has some advantage (e.g., it might be more profitable) over those previously in existence and replaces them (Sugiura 1993). Innovation theory, the process by which an individual, establishment, settlement, or nation receives and adopts something that was not there before (Lowe and Moryadas 1975), covers several disciplines such as economics, anthropology, and sociology (Carlstein 1978). In geography, "the salient feature of its innovation theory is concentrated on the spatial movement of socio-cultural elements, their propagation, transmission, and communication from place to place" (Carlstein 1978, 147). ***Diffusion of innovation*** examples include the spread of such diverse things as the printing press before and after 1471 in England to modern day advancements such as cable television, highway improvements, and electrical power. As Berry (1993, 395) explains, macro temporal and spatial scales are necessary to understand the diffusion process of many of these

innovations: "Over the past two centuries, the progress of economic history has been marked by the rise and fall of successive technological systems... with the interval from takeoff of new innovations to market saturation by the new technologies averaging some fifty to sixty years."

A classic example of an innovation spreading continuously and contiguously across the landscape is the introduction of the gas-light in England in the early nineteenth century. Referred to as the "colonization of night time" (Parkes and Thrift 1980, 282), the diffusion of coal gas light began in 1820 where it first appeared in Pall Mall, London and spread to all major cities in Britain over the next twenty years or so. Electricity, possibly one of the most influential innovations in modern society, has exhibited hierarchical spatial diffusion patterns where the innovation spreads from a first adopter city (e.g., Japan's Tokyo Electric Power Company, started in 1887), to lower-ranking cities, towns, and eventually villages (e.g., Kobe, Osaka, Kyoto, and Sapporo) (Sugiura 1993). As with the colonization of North America, fundamental agrarian innovations also diffused across the landscape. Between 1680 and 1740, Chesapeake planters, in response to a beleaguered tobacco economy, introduced agricultural practices such as shifting cultivation, crops such as corn and wheat, and massive importations of slave labor. The introduction of wheat, corn, and wet rice by colonists in Pennsylvania and the Carolinas eventually extended from Massachusetts to Georgia (Earle 1992). Other examples of innovation diffusion include some controlled by a governing body, such as the strategic introduction of new sugar cane varieties to the Caribbean islands around the turn of the twentieth century. Britain's Royal Commission of 1897 organized the diffusion of new cane breeding beginning with Barbados, the center of innovation in the sugar industry. Over the course of fifty years, new Barbadian varieties of sugar cane were introduced, flourished, and eventually declined on the islands of the Caribbean (Galloway 1996).

Perhaps the most prominent and dramatic spatiotemporal process is the *diffusion of culture* (Morrill 1968). As the first Europeans migrated to and settled areas in the eastern

United States, their ideas, customs, and culture became salient features of the landscape as well. As Hudson (1988, 395) states rather succinctly and effectively, "maps of cultural diffusion are maps of migration." Cultural diffusion, which occurs at slightly smaller scales than innovation diffusion, includes such diverse subjects as the growth of Protestantism in England in the mid sixteenth century (Bertin 1983), Rotary clubs, divorce reform, and rumors (Parkes and Thrift 1980). Communication and interaction, serving as the catalysts for many of these spreads, have a point-to-area spatial structure, particularly information transmission by the mass media including radio, television, magazines, and newspapers, all of which have a distinct spatial hierarchy (Jakle, Brunn, and Roseman 1976), as well as by word of mouth (Parkes and Thrift 1980). For example, in 1891 a rumor spread throughout Japan that a fire in an office building was caused by a short circuit in the electrical wiring and the public began to regard electricity as dangerous. The growth of electrical companies slowed for a year or two following this accident after which the rumor was disproved and the companies gradually spread to smaller towns and villages (Sugiura 1993). The same spatial pattern was exhibited by the Panic of 1837. During the month of May in 1837, banks first stopped converting banknotes into specie (i.e., gold and silver) in Natchez, Mississippi. Although the information transmission was word of mouth, and subsequently, newspaper, within two days banks in Tallahassee, Florida, Montgomery, Alabama, and New York City followed suit.

The concentrations of firms is another example of a cultural diffusion phenomenon. The number of selected Korean-owned business firms in Koreatown and its outlying areas in Los Angeles, California experienced a three hundred percent growth rate between 1975 and 1986 with the area experiencing an increased concentration of firms in the central area and a deconcentration toward a broader local area (Lee 1995). This dualistic pattern of growth can also be applied to the diffusion of Wal-Mart stores over larger scopes of analysis. Wal-Mart Stores, Inc., the nation's largest retailer, has exhibited a pattern of reverse hierarchical diffusion where the phenomenon spreads from small towns to larger

cities and metropolitan areas. Wal-Mart has diffused from its first store opening in northwest Arkansas in 1962 to over a hundred store openings in Arkansas and adjacent states by 1974, to over five hundred new stores throughout the deep south and southern plains by 1984, to over eight hundred openings throughout the U.S. by 1990 (Graff and Ashton 1993).

Some forms of *diffusion of disease* are also examples of continuous areal phenomena. To understand how a disease moves through a human population, comparable scale references (e.g., households and days or countries and years) should be adopted. The actual process of communicable disease transmission at micro spatial scales (e.g., among households and small villages) occurs in a spatially contagious manner (i.e., "neighborhood diffusion") and over small time frames such as days and weeks (Wilson 1993, 281). However, an epidemic (a disease that invades a population and spreads through it at particular times) is often observed using broader spatial and temporal contexts. Occurring through social and, therefore, spatial networks and depending on the presence of critical numbers of susceptible individuals to maintain the chains of transmission (Wilson 1993), epidemics exhibit intricate geographical patterns built upon a series of interconnected and nested contagious processes occurring at different levels of human interaction (Wilson 1993). A good example of this spatial and temporal complexity is the spread of the AIDS virus world wide over the last decade or so.

Acquired Immunodeficiency Syndrome (AIDS) reflects a hierarchical nodal pattern moving from major urban areas in Africa to other major urban areas such as Paris, New York, and Los Angeles (Shannon and Pyle 1989). The epidemic has spread in a fashion characteristic of most sexually transmitted diseases, i.e., spreading outward from larger to smaller metropolitan areas, and from those cities to adjacent suburban areas. In the case of the AIDS epidemic, radial diffusion pathways have been guided by concentrations of populations behaviorally at risk and located at increasing distances from point of origin to the infection (Shannon and Pyle 1989). The spread of AIDS within the United States,

identified by aggregate effects of several years of reporting, has occurred throughout the northeastern U.S. Megalopolis, beginning with the New York City node in the early 1980's, and expanding along the Northeastern seaboard and inland (Shannon and Pyle 1989).

Other kinds of geographic phenomena are similar to diffusion processes in their spatial and temporal movements and include *acculturation*, the process by which an ethnic group changes in order to function in the host society, and *assimilation*, the loss of all ethnic traits and complete blending into the host society (Jordan and Rowntree 1986). Acculturation is usually the first and easiest stage of assimilation; new immigrants tend to locate in ethnically concentrated zones characterized by large absolute numbers of immigrants showing little English language ability, low educational attainment, low rates of naturalization, and low income levels. After the first few years of assimilation in these ethnically concentrated areas in the older centers of a city, individuals and groups with greater economic resources tend to move out of the concentrated zones and into adjacent areas with less ethnic concentrations called 'dispersed zones.' As more years follow and more cultural and social assimilation occurs, immigrants may move further away into less central areas with newer, better housing (i.e., highly dispersed zones), where the dominant population is U.S.-born white Americans. The model of spatial assimilation, as applied to the United States, focuses on the direct connections between cultural, economic, and spatial assimilation; immigrants who share a culture, settle together initially for mutual support, then leave that concentration and find homes among English-speaking U.S. residents as they become more familiar with the country's culture, find better jobs and earn more money (Allen and Turner 1996). The patterns of spatial assimilation reflect a distance gradient: as distance from the ethnic concentration increases, the relative assimilation of individuals should also increase. These processes of acculturation and assimilation can be interpreted at micro spatial scales and macro temporal scales with which the movements of not only the groups of new immigrants but of the adaptation process as well flow across urban then suburban areas over a period of several years, only to begin the cycle again at the urban center with new groups of immigrants.

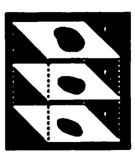
Other examples of phenomena moving continuously in an areal fashion are some types of ***regional boundary changes*** and include movements associated with cultural regions, urban sprawl, and land use and cover changes. Geographically speaking, the landscape is subject to demarcation and division by its culture, use, and cover as a means of identifying, understanding, inventorying, and monitoring the earth. These boundaries or land divisions, albeit fuzzy and often subjective, comprise and identify areas or regions of space and often change with the passage of time. Spatially, changes to a cultural region's boundaries can occur in areas as small as neighborhoods (e.g., New York's Little Italy) to areas encompassing several countries (e.g., Scandinavia). Generally speaking, movement of a cultural landscape occurs slowly and may even be considered evolutionary; inhabitants tend to be unreceptive to radical change and generally strive to preserve a landscape's original features (Falah 1996). This rate of cultural transformation is typical for many regions and is best understood using a macro temporal scale with which spatial changes to the region are not necessarily noticeable on a day-to-day basis but rather over a period of many years. However, changes to a cultural landscape's spatial extent can occur in a very rapid and dramatic fashion. For example, Falah (1996) examined the exodus/expulsion of the Palestinian people during the 1948 war that preceded the establishment of the State of Israel. The Israeli military adopted a strategy of "total war" to systematically eliminate the Palestinian's attachment to their habitat (i.e., a strategy of "de-signification") (Falah 1996, 257). Part of this transformation process where the cultural imprint of the Palestinians was removed from the landscape involved the annihilation of place or "landscape erasure" (Falah 1996, 258). Historic buildings and other treasures of civilization were destroyed. The depopulation of Palestinians by the Israelis over the course of a year served as a catalyst for the transformation of Palestine's cultural landscape. This example of a region's movement (in this case, the quick and radical obliteration of cultural space) is understood clearly at meso spatial and temporal scales.

Regional boundary changes occurring in land use and cover are also considered continuous areal movements, especially when viewed over a long time period. Primate urban growth (i.e., high rates of natural increase in urban areas and high levels of in-migration from rural areas) helps create *urban sprawl*, a spatial phenomenon where new settlements located around an older urban core (CBD) become more populated and urbanized as a result of high rates of population growth. Metropolitan landscapes transform spatially as cities have changed from small, isolated population centers to large areas of connected economic, physical, and environmental features on the landscape (Buchanan and Acevedo 1996). This expansion or movement of urbanization into outlying areas of a city is clearly evident when examining the boundaries of the affected area over a period of several years. For example, in looking at a series of maps depicting the growth stages of Cairo, Egypt, over the last ten years, the areal spread of urbanization is evident by the increasingly larger space demarcated as urban surrounding the city (Stewart 1996).

Not only is urban sprawl a type of cultural and land use regional boundary change, it also represents changes to the natural land cover of an area. Changes in a landscape's land use, including marginal alterations such as diversifying an agricultural parcel of land to more dramatic changes such as transforming a fallow field to multiple family residences, "profoundly influence" the native vegetative cover of a landscape (Medley, McDonnell, and Pickett 1995, 159). Urbanization causes a loss of natural vegetation and open spaces as well as a general decline in the spatial extent and connectivity of wetlands, wildlife habitat, and agricultural lands (Buchanan and Acevedo 1996). Also influencing natural land cover are anthropogenic processes associated with urbanization such as elevated levels of atmospheric CO_2 resulting from deforestation and the combustion of fossil fuels (Knapp and Soule 1996). In studying the influence of land use on the ability of a wind-dispersed tree species to migrate in response to climatic warming, Dyer (1994) modeled the dispersal of the loblolly pine in two areas in the eastern United States, each distinguished by the intensity of the surrounding land use. Simulated migration through the heavily forested study area was projected to occur in 940 years while 1,740 years are projected for the loblolly pine to migrate through the metropolitan study area. Similar research by Knapp and Soule (1996) of a transect extending from New York City to northwestern Connecticut indicated that as measures of urbanization (i.e., human population density, highway traffic volume, density of the road system, and urban-residential land uses) declined directly with distance from the urban core, the forest-landscape structural characteristics increased with distance.

Other land use/cover changes may be due to agricultural practices. Zweifler, Gold, and Thomas (1994) studied social survey and air photo time series data spanning several decades of the Dominican Republic to gain both a temporal and spatial understanding of the area's land use evolution from uninhabited wilderness to one of Latin America's most severe examples of hill land degradation. Referring to the region's continually changing land use/cover pattern as an "evolutionary process," the authors describe a land use continuum involving three distinct stages, each marking changes in the region's landscape for such land use classifications as grass/brush (11% down to 2%), forested canopy (12% down to 5%), and coffee plantations (39% up to 63%) (Zweifler, Gold, and Thomas 1994, 53). The boundaries of each of these land use categories were seen to have continuously shrunk or expanded over the time period examined. Regardless of the causes of land use/cover changes in any plant community, the important thing to note is that continuous change in vegetation composition and dominance is a normal and ever present component of ecosystem dynamics (Knapp and Soule 1996). As such, many natural land cover boundaries are considered continuous areal movements when interpreted over periods of tens to thousands of years.

Sometimes, however, spatial change to an area's natural land cover may occur very rapidly over a short period of time due to unforeseen events. As one such phenomenon, *forest fires* can be described as continuous areal movements; once ignited a fire quickly spreads across a vegetative area, often moving from the point source(s) in an outward fashion. The spatial and temporal dynamics of this phenomenon are most evident using micro and meso scale references, where the areal spread is easily identified over tens to hundreds of miles within several days. Factors such as wind speed and direction, as well as natural and human features on the landscape, will affect the rate and spatial extent of the fire's expansion. Nonetheless, the fire does spread in a continuous areal fashion from its source(s) and does not stop advancing until abated in some way. However, some forms of spatial expansion are not always temporally continuous, as discussed next with class 8, cyclical areal movements.



Class 8 Cyclical Areal Movements

A second class of geographic phenomena that spreads out across the landscape is cyclical areal movement. Some *regional boundary changes*, as well as outbreaks of *gypsy moth defoliation* and *diseases* such as measles, dysentery, typhoid, and foot-and-mouth epizootic, are all examples of how geographic phenomena move across a population or landscape, affecting large contiguous areas of space in a cyclical fashion (Figure 4.9). These areal movements occur with a fair regularity ranging from a small periodicity of just a few days to longer periods of several to hundreds of years. *Regional boundary changes*, as geographic phenomena that are interpreted to move in areal fashion over the landscape, are sometimes cyclical. A region is a spatially dynamic entity as its spatial demarcations often change over time. As with the case of administrative or political boundaries, the delineation of space with borders is somewhat rigid and usually clearly defined. For example, every ten years the Census Bureau officially makes amendments to its political/administrative boundaries such as census blocks, blockgroups, tracts, minor civil divisions, and Congressional districts. Changes to the borders of these regions are

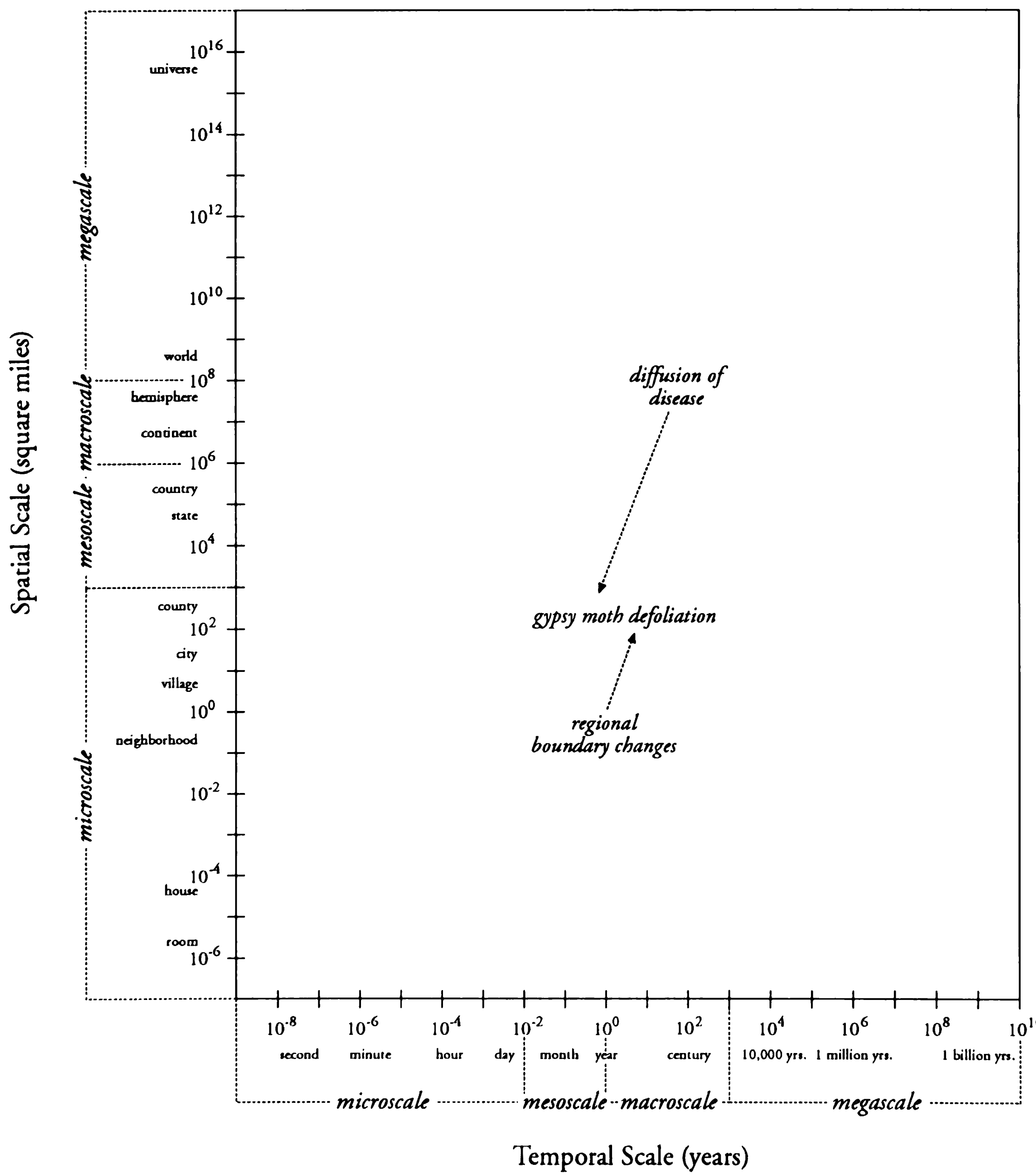


Figure 4.9 Scale Paradigm of Cyclical Areal Movements.

apparent at micro spatial and macro temporal scales.

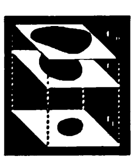
Cyclical movement of land use boundaries are also noted in many agricultural regions of the world. Moran's (1993, 698) study of wine appellation in France suggests that major wine-producing areas in the region are highly localized, with each variety of grape having its own distinctive geographic pattern: "the definition of territory is central to the French wine appellation... its primary aim is to permit the association of a particular wine with the territory from which it originates." However, the author further notes that the most prestigious wine-grape varieties are beginning to disperse. For instance, until the 1980's, Cabernet Sauvignon was overwhelmingly localized in Bordeaux (southwest France), but has dispersed and moved into more south central areas of France, such as the Languedoc-Rousillon, Provence, and Midi regions.

Gypsy moth defoliation and other pest infestations are also examples of cyclical areal movements. Gypsy moths, believed to have first evolved in the Far East, were accidentally introduced into the United States in 1869 when some escaped from a laboratory experiment in silk worm breeding (Pond 1992). From its now infamous origination point on Myrtle Street in Bedford, Massachusetts, the insect occurs today in more than half of the states in America, and is firmly entrenched from Canada south to North Carolina and from Ohio west to central Michigan, with isolated infestations in a number of other states. Although large areas of forested land are altered each year from gypsy moth larvae feeding, *contiguous* patches of stripped canopy foliage (i.e., defoliation) form a mosaic pattern at micro spatial scales (Thurber, McClain, and Whitmore 1994). Gypsy moth defoliation is a highly cyclical phenomenon at meso and macro temporal scales; not only is the reproductive cycle of the larvae cyclical (yearly), but the regional outbreaks occur in a predictable fashion as well. The number of acres infected from 1967 to 1991 simulate an "ebb and flow;" gypsy moth populations advance to new areas, build up to outbreak numbers and then wane for a number of years, only to repeat the cycle over and over, usually every four to five years (Pond 1992, 24).

Other pest infestations such as the western spruce budworm, fir-engraver, and Douglas-fir beetle are also highly cyclical, spatially contiguous phenomena. The Blue Mountains of northeastern Oregon have experienced massive tree mortality and damage over the past decade due to such pest infestations. A major outbreak peaked in 1986, declined until 1989 when another outbreak peaked, which then subsided in 1992. As with any infestation, once the pests are introduced, the close proximity of trees in forested areas make it easy for the infestations to spread rapidly from one tree to the next (Green and Cosentino 1996).

Another geographic phenomenon that sometimes acts as a cyclical areal movement is the *diffusion of disease*. Understanding the cyclical nature of disease spreads requires employment of comparable scale references in both time and space that can vary from micro to macro scale. The spatial descriptions of epidemics in historical populations are typically rendered at larger regional and state scales over the course of many, many years. This approach, as Wilson (1993, 276) suggests, is useful since "it shows the ebb and flow of epidemics across human space and demonstrates the temporal sequence of infection in this space." Many infectious diseases such as measles, dysentery, and typhoid act as 'recurrent wave models,' where the phenomenon may always be present in a population, but the prevalence of which oscillates on a cyclical basis (Carlstein 1978). Time and space correlograms of weekly measles data in southwest England between 1966 and 1970 showed that the disease did not die out in the country, but rather flared up in major epidemics approximately every two years. A similar wavelike form was also shown in thirty-three major measles epidemics in Denmark over a hundred year period from 1868-1968 (Haggett 1975). Cyclical patterns of disease also occurred with the colonization of the Chesapeake Bay by the Virginia Company of London beginning in the spring of 1607. The first outbreaks of dysentery and typhoid came in the summer of 1608, and returned every summer thereafter until the colony's dissolution by the Crown in 1624. The only break in this cycle occurred between 1613 and 1616 when Sir Thomas Dale, recognizing the causal link between water supply and mortality, dispersed the settlement, but his actions were overturned by company agents freshly arrived in Virginia.

Another disease phenomenon shown to exhibit cyclical areal diffusion was the foot-and-mouth epizootic in Great Britain between 1967-68. The disease which affected many livestock including pigs, sheep, and cattle had a much shorter periodicity than that of measles in the human population. The trend of the epizootic was that of a rapid initial build-up, a sudden peaking, then a much slower decline. The pattern about this trend of outbreaks was cyclical with a period of about eight days (Tinline 1972). The outbreak also exhibited areal spread; the movement of the epizootic was traced by plotting the daily center of gravity of the outbreaks and a general northeast contiguous movement across the countryside was noted. This was due largely to airborne spread with wind serving as the major mechanism for the dispersal of the disease.



Class 9 Intermittent Areal Movements

Intermittent areal movements occur contiguously across an area or region in an irregular fashion and are associated with such geographic phenomena as ***regional boundary changes***, ***desertification*** and ***military deployments*** (Figure 4.10). One type of intermittent ***regional boundary change*** is political or administrative in nature. As Bertin (1983, 342) states, "the movement of political borders... is a discontinuous movement." Land ownership parcels, national borders, and voting, school, and emergency service districts are all examples of defined regions whose boundaries often shift over time. The boundaries of Nazi Germany between 1935 and 1939 were altered and solidified by, of all things, the Autobahn's development (Rollins 1995). The highway network which the Nazis referred to as "an ideological consolidation of the nation," served as a mechanism by which the "far flung corners of Germany" were linked into one concrete network (Rollins

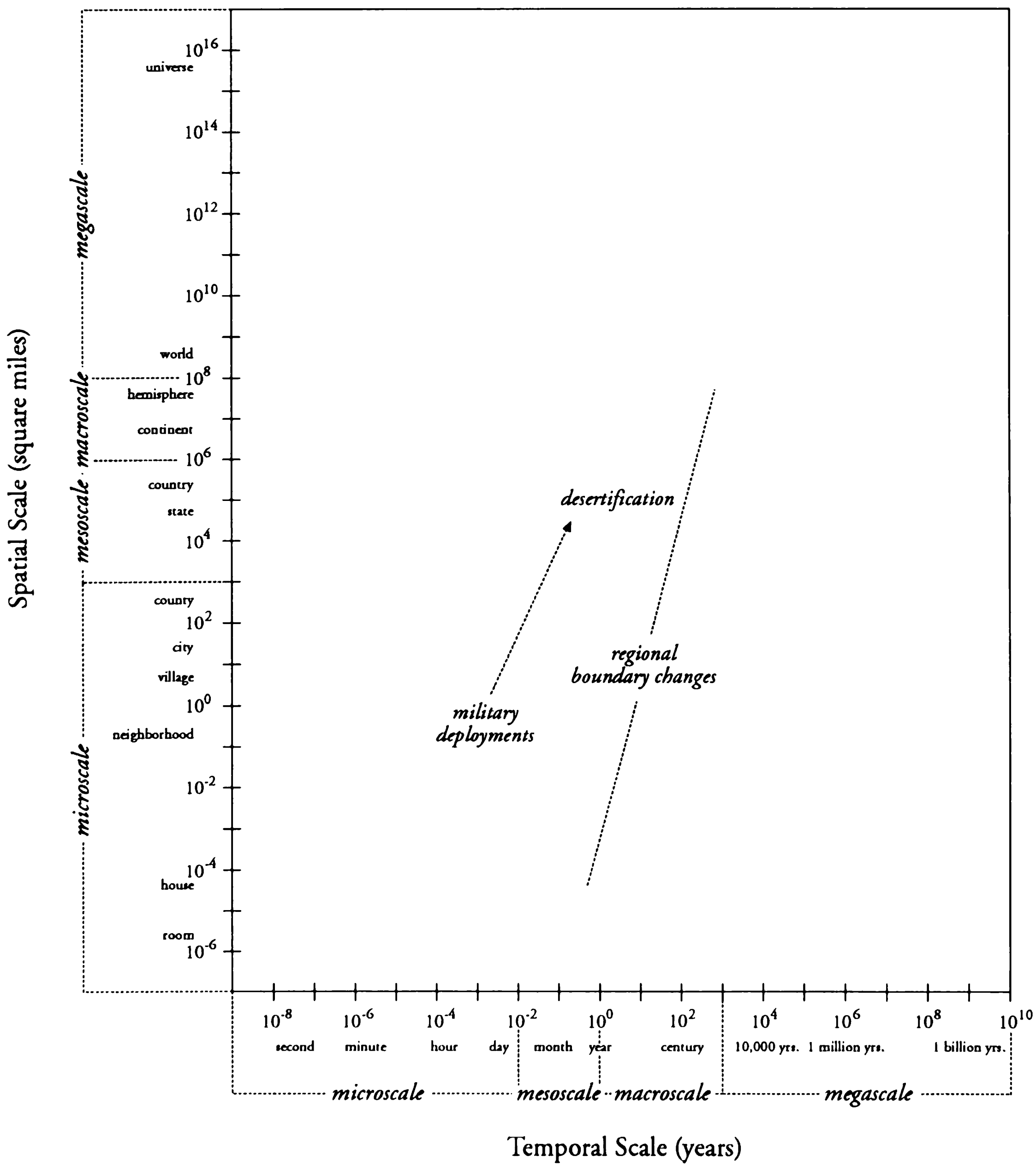


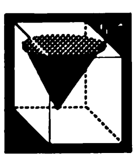
Figure 4.10 Scale Paradigm of Intermittent Areal Movements.

1995, 494-495). More recently, the "fundamental geopolitical transition" associated with the collapse of the Soviet Union has resulted in the creation of no less than fifteen new sovereign states, with the prospect of further disintegration of the former Republic (Bradshaw and Lynn 1994, 442). The spatial scale of political or administrative regions varies considerably and may fall within the micro, meso, or macro spatial scales, where delineated areas may be as small as a quarter of an acre or less (e.g., individual land parcel) to as large as the Russian Federation, currently over six-and-a-half million square miles. Temporally, these boundaries may change infrequently and are often identified at macro scale as moving over a period of years.

Economic regions also have intermittently moving boundaries, though not as tangible as its administrative counterparts: "Unlike political space, economic space is more amorphous in that its boundaries tend to be fuzzy and permeable" (Lowe and Moryadas 1975, 9). Generally, economic borders are small (micro to meso) in spatial scale and move over periods of years. For example, Moore (1994), in examining the spatial dynamics of Appalachia's economic development which spans more than twenty-five years of regional planning strategies, uses core-periphery models to provide a useful construct for explaining changes and contrasts in geographic patterns of income within Appalachia. This approach allowed a clear spatial illustration of regional dynamics and led to the suggested redefinition of the Appalachian Regional Commission (ARC) regions).

Another geographic example of an intermittent areal movement is ***desertification.*** A term used to describe the widespread distribution of land degradation in dryland environments whereby land is rendered sterile with respect to agricultural production in a manner that is irreversible in practical human terms, desertification is a phenomenon that involves complex earth-surface systems components (e.g., climate, soils, vegetation, etc.). As Phillips (1993, 638) notes, areas being degraded are changing as unpredictably as the weather: "these systems are subject to potentially unpredictable, chaotic behavior, in addition to irregular internal climate forcings." Desertification is best understood using meso spatial extents and macro time frames.

A final geographic phenomenon that exemplifies intermittent areal movement is *military deployment.* Generally, deployments occur across relatively small spatial extents over a course of a day to several weeks. For example, in the numerous battles during the Civil War in the United States, deployment of ground troops, as a means of overtaking a fort, city, or other key locale, usually began as linear movement, but often led to an areal encroachment of troops on all sides (i.e., 'surrounding the enemy'). In such campaigns as Chancellorsville and Gettysburg, the movement of troops was intermittent and occurred over just a few days (McPherson 1988). However, the deployment of troops sometimes occurred over a much longer time frame, as was in the case of the Vicksburg Campaign and subsequent siege which lasted over three months (Kennedy 1990).



Class 10 Continuous Volumetric Movements

The last three classes of geographic movement involve volumetric flows and movement. Volumetric phenomena take on a three-dimensional form as they move across space and through time. Continuous volumetric movements (Figure 4.11) encompass many of the earth systems processes, primarily due to the fact that most volumetric features in geography consist of the natural states of matter: solids, water, and/or gas. Studies of the planet earth fall into broad categories that embrace the solid lithosphere, water in the liquid hydrosphere and frozen cryosphere, the mainly gaseous atmosphere, and the life forms of the biosphere. Phenomena caused by lithospheric movements, such as *continental drift, a volcanic eruption, an earthquake, a tsunami, glaciation, rock transformation, soil creep,* and *blowout formation,* as well as the *rotation of the earth* all involve continuous volumetric movement of the solid earth realm. Biospheric earth systems, such as the *hydrologic cycle,* encompass all living organisms of the earth and the

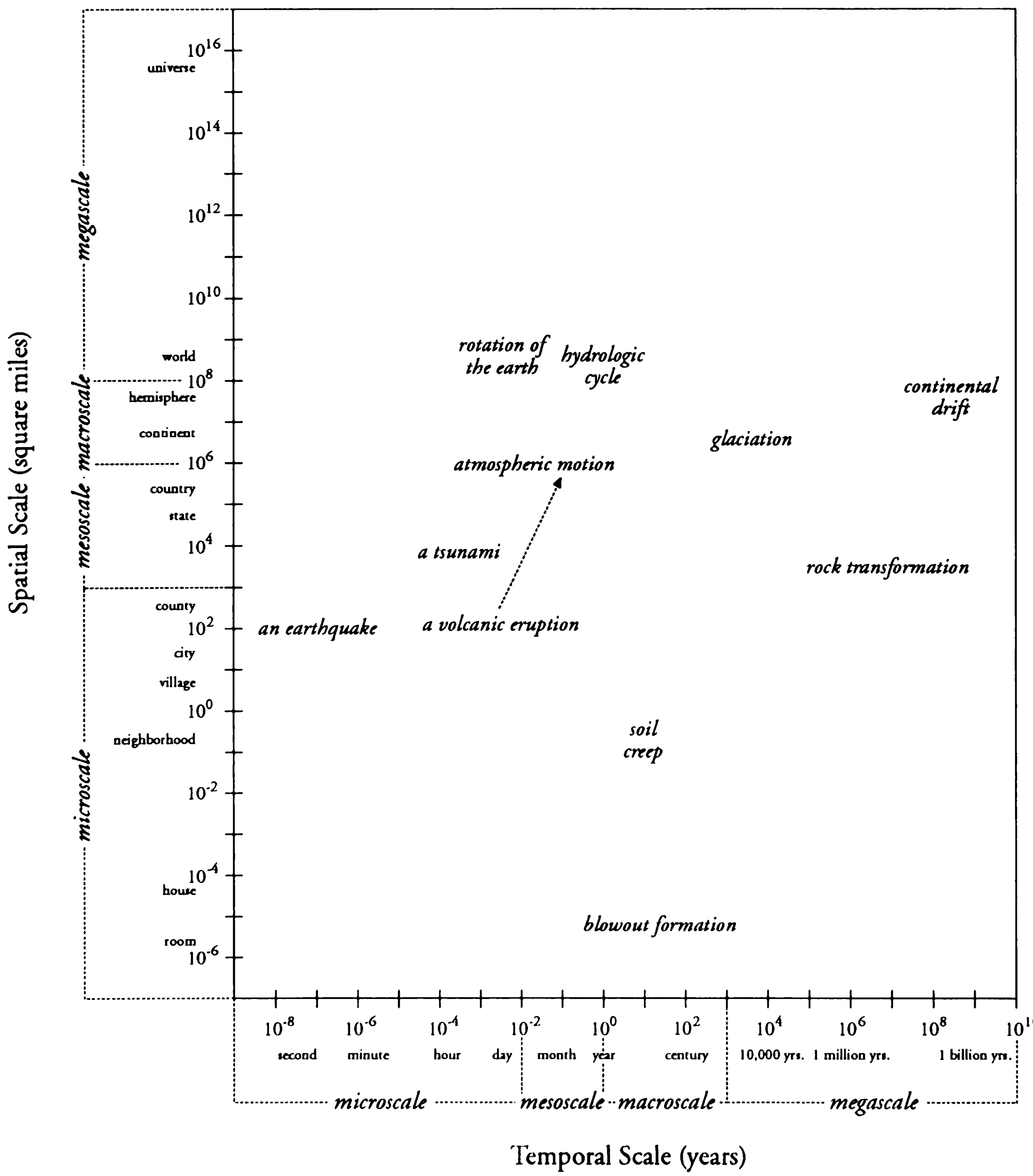


Figure 4.11 Scale Paradigm of Continuous Volumetric Movements.

environment with which they interact. *Atmospheric motion* involves movement of air in the earth's atmosphere due to processes such as climatic and ocean circulation and global radiation. Continuous interchanges among each of these 'spheres' produce an integrated environment, with the entire earth realm acting as one closed system, continually moving in space and time. A closer examination of these naturally-occurring phenomena will reveal their continuous volumetric nature.

Plate tectonics is the catalyst for many continuous volumetric movements such as continental drift, a volcanic eruption, an earthquake, and a tsunami. Plate tectonics is the general theory encompassing lithospheric plates and their relative motions and boundary interactions. The earth's lithosphere, which includes the upper part of its mantle as well as the crust, ranges in thickness from twenty-five to fifty miles deep. The lithosphere is broken into large fragments called lithospheric plates, which are typically of continental dimensions and capable of moving independently of the plates that surround it. A long term effect of tectonic activity is the phenomenon *continental drift*, which refers to all forms of breaking and bending of the entire lithosphere, including the crust (Strahler and Strahler 1984). As a continuous volumetric movement, continental drift, which refers to the separation of the continents, "involves a spatial phenomenon that integrates all time, all space, and all physical processes for an entire planet" (Dobson 1992, 188-189).

Various theories have existed about the movement associated with continental drift. In the early twentieth century, Alfred Wegener, a German meteorologist and geophysicist, reconstructed a super continent called 'Pangaea' which existed intact about 300 million years ago in a period of geologic time called the Carboniferous Period (Strahler and Strahler 1984). Wegener visualized this large land mass slowly rifting apart, until the continents and oceans, as we know them today, were created. Although Wegener's theory was scoffed in the 1920's and 1930's, within forty years plate tectonics emerged as a leading theory. Some have suggested the continents have moved laterally while circulation models suggest a circular form of movement that could account for repeated collisions and separations of adjoining continents (Dobson 1992). The modern interpretation is that continental drift involves entire lithospheric plates, much thicker that merely the outer crust of either the continents or the ocean basins. Plate movements over a soft plastic asthenosphere have allowed the continents to be carried according to the general timetable postulated by Wegener (Strahler and Strahler 1984). Regardless of the direction, speed, and actual paths of the movements, all theories of continental drift agree that the continents, as macroscale three-dimensional volumetric objects, have moved spatially over the earth in one continuous geologic time-frame.

Another example of a continuous volumetric movement is a *volcanic eruption.* Volcanoes, conical or dome-shaped structures built by the emission of lava and its contained gases from a constricted vent in the earth's surface, vary in form and dimension depending on the type of lava and the presence or absence of tephra, the ejected solid fragments ranging in size from gravel and sand down to fine silt. The nature of a volcanic eruption, whether explosive or quiet, depends on the type of magma; felsic lavas have a high degree of viscosity, hold large amounts of gas under pressure, and result in lavas producing explosive eruptions while mafic lava is highly fluid, holds little gas, and produces relatively quiet eruptions with lava traveling over long distances in thin layers (Strahler and Strahler 1984).

Spatially, a volcanic eruption can affect microscale areas from a hundred square miles up to macroscale spatial extents covering the western half of the United States and beyond. Clouds of incandescent gases, also known as 'glowing avalanches,' can soar to heights of more than 60,000 feet before descending down the flank of the volcanic cone, such as the 1902 eruption of Mount Pelee (Strahler and Strahler 1984). The descent of millions of tons of ash, cinders, and lava can spread out over vast areas of several hundred acres. Debris flows, called 'lahars,' are flash floods of semiliquid mud, rock, and ice that surge down the slopes with terrifying speed and, as the Colombian farming community Armero experienced in 1985, can bury the surrounding landscape with over thirty feet of debris (Krakauer 1996). Temporally, a volcanic eruption can be analyzed in both the microscale and the mesoscale domains. While the actual eruption may only last several minutes, the aftermath associated with the eruption can linger for several days, weeks, even months, as was the case with the 1815 eruption of Mount Tambora in Indonesia. The year following that eruption was known as "the year without a summer" in the United States and Europe due to the estimated 150 square kilometers of ash that had been ejected into the atmosphere (Critchfield 1983, 241).

An earthquake is another geographic phenomenon that occurs in a continuous volumetric fashion. Like ripples produced when a pebble is thrown into a quiet pond, seismic waves, produced by sudden movements along faults, gradually lose energy as they travel outward in widening circles from a focus, or a point of sudden energy release. Strahler and Strahler (1984) stress that an earthquake is not a cyclical or patterned event, even though it is inevitable. An earthquake falls within the microscale domain, both in time and in space, as the phenomenon typically lasts for a duration measured in seconds and adversely affects a relatively small geographic area, such as part of a city or county.

A tsunami, a seismic sea wave, is an important environmental hazard associated with a major earthquake and is interpreted as a continuous volumetric phenomenon. Occurring over several thousand square miles (meso spatial scale) and lasting less than one day (micro temporal scale), a tsunami or 'tidal wave' is a train of water waves often generated in the ocean at a point near the earthquake source by a sudden movement of the seafloor. The waves move over the ocean in ever-widening circles and cause a rise of water level when it arrives at a distance coastline. Wind-driven waves, superimposed on the heightened water level, allow the surf to attack places inland that are normally above the reach of waves. For example, the seismic wave of 1933 in the Pacific Ocean caused waves to attack ground as high as thirty feet above normal tide level, causing widespread destruction and many deaths by drowning in low-lying coastal areas (Strahler and Strahler 1984).

Other examples of continuous volumetric geographic phenomena include many geomorphological processes such as glaciation, rock transformation, soil creep, and blowout formation. Geomorphological analyses all deal with the fundamental components of landform evolution and weathering (Gares and Nordstrom 1995). Weathering, the general term applied to the combined action of all processes causing rock to be disintegrated physically and decomposed chemically because of exposure at or near the earth's surface, involves a continuous agitation in the soil and regolith over very long time intervals (Pope, Dorn, and Dixon 1995). *Glaciation,* the total process of glacier growth and landform modification by glaciers, is one example of landform evolution that occurs progressively (Strahler and Strahler 1984). A glacier may be defined as any large natural accumulation of land ice affected by present or past motion, the size, speed, and volume of which may vary considerably. Large ice sheets, such as the Greenland Ice Sheet with an area of 670,000 square miles, generally move just a few centimeters per day while an active alpine glacier with a much smaller volume may move at a rate of several meters per day. Some alpine glaciers experience episodes of very rapid movement, described as 'surges', and the glacier may develop a sinuous pattern of movement (i.e., "galloping glaciers") (Strahler and Strahler 1984, 352-353). Regardless of these spatial and temporal variations, glaciation is best understood as a continuous volumetric phenomenon when using macro and mega scale frames, both spatially and temporally.

Rock transformation is another geomorphologic example of a continuous volumetric phenomenon. The process of rock transformation is a total circuit of rock change in response to environmental stress where mineral matter is continually recycled through the three major rock classes (igneous, sedimentary, and metamorphic) (Strahler and Strahler 1984). This 'rock cycle' is in continuous operation over some three million years or more of geographic time (mega time frame) and generally can be said to occur over mesoscale spatial extents.

Also affected by weathering and contributing to landform evolution are continuous sedimentological processes involving soil erosion and deposition such as soil creep and blowout formation (Blewett and Winters 1995). Soil, a natural earth surface layer containing organic and mineral matter, is dynamic as many complex physical and chemical activities are occurring simultaneously within it (Strahler and Strahler 1984). *Soil creep* is the extremely slow downhill movement of soil and regolith as a result of continued physical and chemical weathering (e.g., frost action, unloading), as well as other catalysts such as burrowing animals and earthquakes (Strahler and Strahler 1984). The process is best understood using a micro spatial scale (i.e., a particular location) and a macroscale temporal frame; soil creep is, for the most part, slow-acting and produces effects that are visible only when accumulated over many years, even centuries. Eroded sediments may travel anywhere from three or four kilometers in a hundred years or more, to more than twenty-five kilometers in the same time frame (Beach 1994). The volume of transported sediment can be remarkable in some highly eroded areas such as the Loess plateau in China, where an average of one centimeter of loessal soils are moved each year (Veeck, Zhou, and Ling 1995).

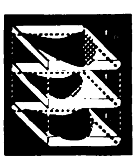
Blowout formation involves the development of depressions in dune systems as a result of deflation, a process where loess sediments lying on the ground surface are lifted in the air or rolled along the ground by wind (Strahler and Strahler 1984). Like many geomorphic features, a blowout evolves as a result of process/form interaction representing adjustments between wind speed and direction, topography, and vegetative cover. Gares and Nordstrom (1995, 17), in studying three blowouts located within a twelve kilometer long section of New Jersey's Island Beach State Park, note that blowouts occur over microscale spatial extents (approximate averages of fifty square feet in surface area and five feet deep), and evolve through distinct morphological stages over the microscale time frame of one to two decades.

Like solid earth matter, water is analyzed and understood in three dimensions and is considered to be a continuous volumetric movement: "the flow of water, measured as cubic feet per second... incorporates both volume and time" (Lowe and Moryadas 1975, 159). The *hydrologic cycle*, or global water balance, can be treated as a closed material flow system in which water moves through the atmosphere and oceans and upon or beneath the earth's land surfaces in a series of processes such as condensation and precipitation, infiltration and runoff, and evaporation and transpiration. The hydrologic cycle should be viewed with a yearly temporal frame and on a global spatial scale where the "water of oceans, atmosphere, and lands moves in a great series of continuous interchanges of both geographic position and physical state (Strahler and Strahler 1984, 165).

Atmospheric motion is yet another example of continuous volumetric movement. Defined for this discussion to include all contributing and interconnected atmospheric system processes, atmospheric motion refers to the continuous "ceaseless motion of the atmosphere," (Strahler and Strahler 1984, 74). Variable forces keep the atmosphere (the envelope of gases surrounding the earth) in a state of continual agitation and include *global radiation*, *climatic and ocean circulation*, *atmospheric pressure*, and *air masses*. Atmospheric motion is best understood with micro and meso temporal scales and meso and macro spatial scales (i.e., viewing the earth's circulation patterns over the mid latitude zone as it moves over the course of a week).

Global radiation, or electromagnetic energy, travels through space at the speed of light and consists of two flows, one of short-wave radiation from the sun and one of long-wave radiation from the earth. Similar to the hydrologic cycle, global radiation is a system by which a state of matter, as a volume, continuously and endlessly moves through space. Critchfield (1983, 83) describes *climatic and ocean circulation* as "analogous to the movement of air in a room by hot radiators or by forced air ventilation;" as long as sufficient differences in air density prevail at different parts of the system, air will continue to flow in response to the pressure gradient. *Atmospheric pressure*, as the main link between solar energy and motion, directly affects world patterns of winds (air motion with respect to the earth's surface), storms, and related phenomena such as sea and land breezes, which are circulation systems common along coasts due to the rising and sinking motion of the air and by a weak return flow at higher levels (Critchfield 1983; Strahler and Strahler 1984). *Air masses*, bodies of air in which the upward gradients of temperature and moisture are fairly uniform over a large area, move from one region to another following the patterns of barometric pressure. The particular air mass properties at a given place may reflect the composite influence of a travel path covering thousands of kilometers and passing alternatively over oceans and continents (Strahler and Strahler 1984). As each of these atmospheric forces suggest, all are uniquely dynamic but they interact with one another to produce one large "kaleidoscope of many motion systems," i.e., *atmospheric motion* (Critchfield 1983, 139).

A final example of a continuous volumetric movement looks at the earth as a whole. The phenomenon of the *rotation of the earth* involves the planet spinning like a top on an axis. To understand rotation, the earth is viewed as a three-dimensional sphere suspended in space, continuously turning in the same direction and at a constant speed. Spatially, the earth falls under the megascale domain with a mass of over six sextillion short tons and a surface area encompassing close to two hundred million square miles (Famighetti 1996). Temporally, the rotation of the earth is best understood using a microscale view, where one earth turn with respect to the sun defines the solar day (Strahler and Strahler 1984). Phenomena such as sunrises and sunsets provide us with the knowledge that the earth is consistently and ceaselessly spinning around on itself.



Class 11 Cyclical Volumetric Movements

Discussion of continuous volumetric movement has shown most natural earth system processes to be continuously evolving and moving through space and time. Cyclical phenomena often occur in response to these continuously moving earth system processes and include phenomena such as *ocean tides*, *beach recovery*, *El Nino*, *flooding*, and some forms of *pollution* (Figure 4.12). *Ocean tides* are caused by the continual diurnal rhythm imposed by the earth's rotation and are a natural phenomenon involving the alternating rise and fall in the large fluid bodies of the earth caused by the combined gravitational attraction of the sun and moon (Strahler and Strahler 1984). The combination of these two forces produces the complex recurrent cycle of the tides; a sequence of two high tides separated by two low tides is produced each day (Famighetti 1996). Ocean tide can be viewed as a cyclical volumetric phenomenon since the rhythmic movement of the ocean water (as a three-dimensional object) yields tide ranges so predictable that the tidal cycle can be referred to as a 'clock' (Strahler and Strahler 1984). Ocean tides are best understood when viewed using micro scales, watching the tide rise or fall on a beach over several hours.

Related to tidal activity is the cyclical geographic phenomenon of *beach recovery*. Beaches are thick wedge-shaped deposits of sand that absorb energy of breaking waves. Beach recovery involves the cutting back of the beach during short periods of storm and the subsequent restoration of sand during long periods of calm ocean waters when waves are weak (Strahler and Strahler 1984). Using standard beach surveying techniques and depth-of-activity rods to monitor the morphology and volume of sediment evolution changes on an estuarine barrier on the Delaware Bay, Jackson (1995, 33) notes the temporal regularity associated with beach recovery: "The results of this investigation support previous findings that document cyclic beach response and swash bar migration during post storm recovery in ocean and lacustrine environments." As a volumetric geographic phenomenon occurring regularly in estuarine environments, the dynamics of beach recovery are best understood in the domain of microscale space and micro to meso scale time.

As described with continuous volumetric movements, large-scale atmospheric and associated hydrologic systems are always in motion. Often times, these systems produce effects that occur rather predictably in nature such as *El Nino*. In response to major changes in oceanic circulation, El Nino is a disruption of the ocean-atmosphere system in the

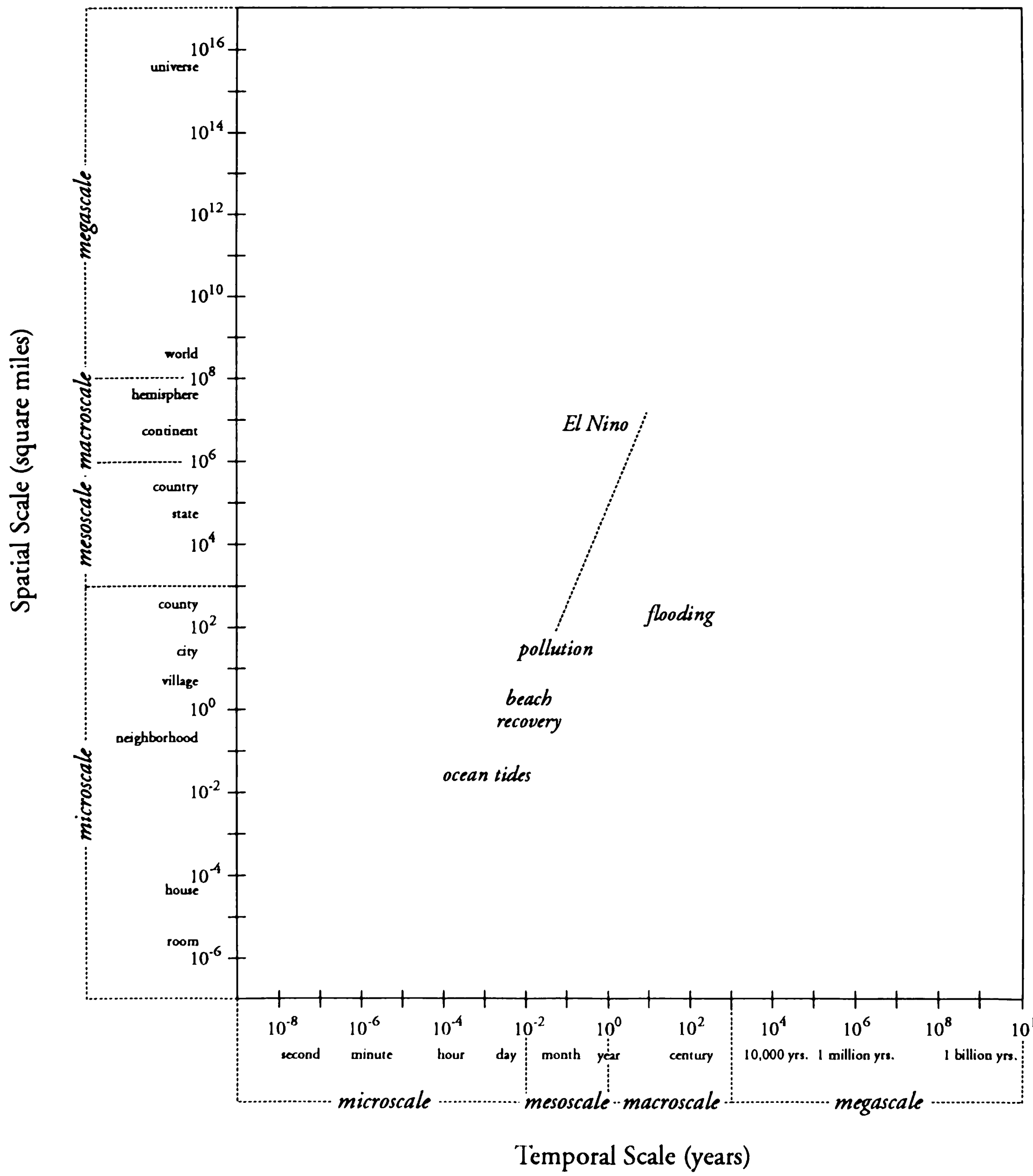


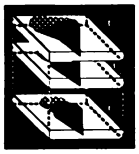
Figure 4.12 Scale Paradigm of Cyclical Volumetric Movements.

tropical Pacific where warm water from the western coast of South America spreads over cold water near the shore, resulting in heavy rainfall in nearby coastal areas (Critchfield 1983). El Nino occurs on a regular basis, usually during February and March, and is best understood at a macro spatial scale. Among the consequences of El Nino are increased rainfall across the southern tier of the United States and in Peru which has caused destructive *flooding*, an activity that has occurred on such a regular basis that it has become predictable (Soreide 1996; Graf and Gober 1992). As a cyclical volumetric movement, flooding occurs quite regularly and can take many forms in nature. 'Flash flooding', the result of copious amounts of rain in a short period of time (Famighetti 1996), can be said to exhibit regular patterns in spatial and seasonal occurrence (Winkler 1992). 'Coastal flooding' is also seasonal and occurs when ocean water is driven inland due to winds generated from tropical storms, hurricanes, or intense offshore low pressure systems. During 'urban flooding,' streets can become swift moving rivers and basements can become death traps as they fill with water; urbanization increases runoff two to six times over what would occur on natural terrain. 'River flooding' is a natural process that occurs seasonally when winter or spring rains are coupled with melting snow, filling river basins with too much water, too quickly, a process that can be magnified due to accumulations of ice at natural or artificial obstructions which stop the natural flow of water.

The geographic phenomenon of flooding is generally best understood using a micro spatial scale and meso and macro temporal scales, where cyclical patterns of the event become evident over the course of many seasons and years. Regularly inundated by stream waters about once a year when the discharge of a river cannot be accommodated within the margins of its normal channel are river floodplains, broad belts of low flat ground bordering the channels on one or both sides (Famighetti 1996; Strahler and Strahler 1984). Such regular inundation is considered a flood, even though its occurrence is expected and does not generally interfere with agriculture or growth of dense forests (Strahler and Strahler 1984). Flood plains are named for the general recurrence interval that can be

expected for certain magnitude flood events: small flood events (less than five year recurrence interval), moderate flood events (five to twenty-five year), and large flood events (greater than a twenty-five year recurrence interval) (Woltemade 1994). Although the periodicity of these more rare and disastrous large flood events does not lend to highly accurate predictions of the occurrence, taken over hundreds of years, a marked regularity does persist.

A final example of a volumetric geographic phenomenon that is cyclical in behavior are some forms of *pollution.* Air pollution is a phenomenon that can occur across a wide array of temporal and spatial scales (micro to macro) and occurs when pollutants (foreign matter) are injected into the lower atmosphere as particulate matter or as chemical pollutants (Strahler and Strahler 1984). Blowing dust is a kind of particulate matter pollutant that is a common phenomenon of dry climates and drought-stricken areas such as the Great Plains of the United States. Blowing dust events, which begin when horizontal visibility falls below eleven kilometers and ends when visibility regained exceeds eleven kilometers (usually within a day), result from the action of strong winds picking up loose earth material and carrying it to great heights and perhaps for great distances as well (Critchfield 1983). Studying dust storms occurring in the southern High Plains of the United States over a forty-two year period, Lee and Tchakarian (1995, 690) found that although the amount of sediment moved per unit force was not found to be consistent among events, a cyclical temporal variability of events was apparently attributed, in large part, to "the seasonal timing of agricultural practices." Ozone pollution, another kind of air pollution, also exhibits cyclical patterns of occurrence. Comrie (1994), in studying the origins and pathways of air masses controlling ozone concentrations in Pennsylvania's Allegheny Plateau forests, found high ozone levels eleven times in a three-year period, but only during the growing season. Although some forms of pollution are cyclical in nature, many do not occur with any regularity and cannot be predicted, as discussed next in the final movement class, intermittent volumetric movements.



Class 12 Intermittent Volumetric Movements

The final class of geographic movement describe intermittent phenomena such as certain forms of *pollution*, *mass wasting*, *volcanic eruptions*, and *earthquakes* (Figure 4.13). Phenomena in this class are complex in both their spatial and temporal components and involve the irregular and unpredictable movement of a volume across space and through time. As discussed in the previous movement class, some forms of *pollution* are cyclical in nature. However, many pollution events are human induced and/or dependent upon many contributing conditions such as the weather, thereby contributing to the unpredictability of an event. While a pollution event may act as a continuous volumetric movement while it is occurring, it is the *phenomenon* of pollution as an unplanned, unpredictable activity that contaminates the earth that is of geographic significance. As a spatially dynamic phenomenon occurring unpredictably in three dimensions (air, water, earth matter), pollution can vary significantly in scale, both spatially and temporally, and understanding such complexities requires scopes of analysis ranging from micro to macro scales.

One type of pollution that occurs irregularly is air pollution. Pollution domes form when pollutants are trapped beneath an inversion lid within the earth's atmosphere that takes the form of a broad dome centered over a city when winds are light or a calm persists (Strahler and Strahler 1984). Pollution domes are fairly common in urban areas and, although they occur more frequently during the summer, they are unpredictable due to the fact that "background meteorological conditions vary on a daily, monthly, and annual basis" (Comrie 1994, 635). Other events of intermittent air pollution may occur as a result of a single catastrophic episode, such as the burning of the Kuwait oil fields, the eruption of Mount St. Helens, and radiation leaks from nuclear reactors, such as the 1979 Three Mile Island meltdown and the 1986 Chernobyl accident.

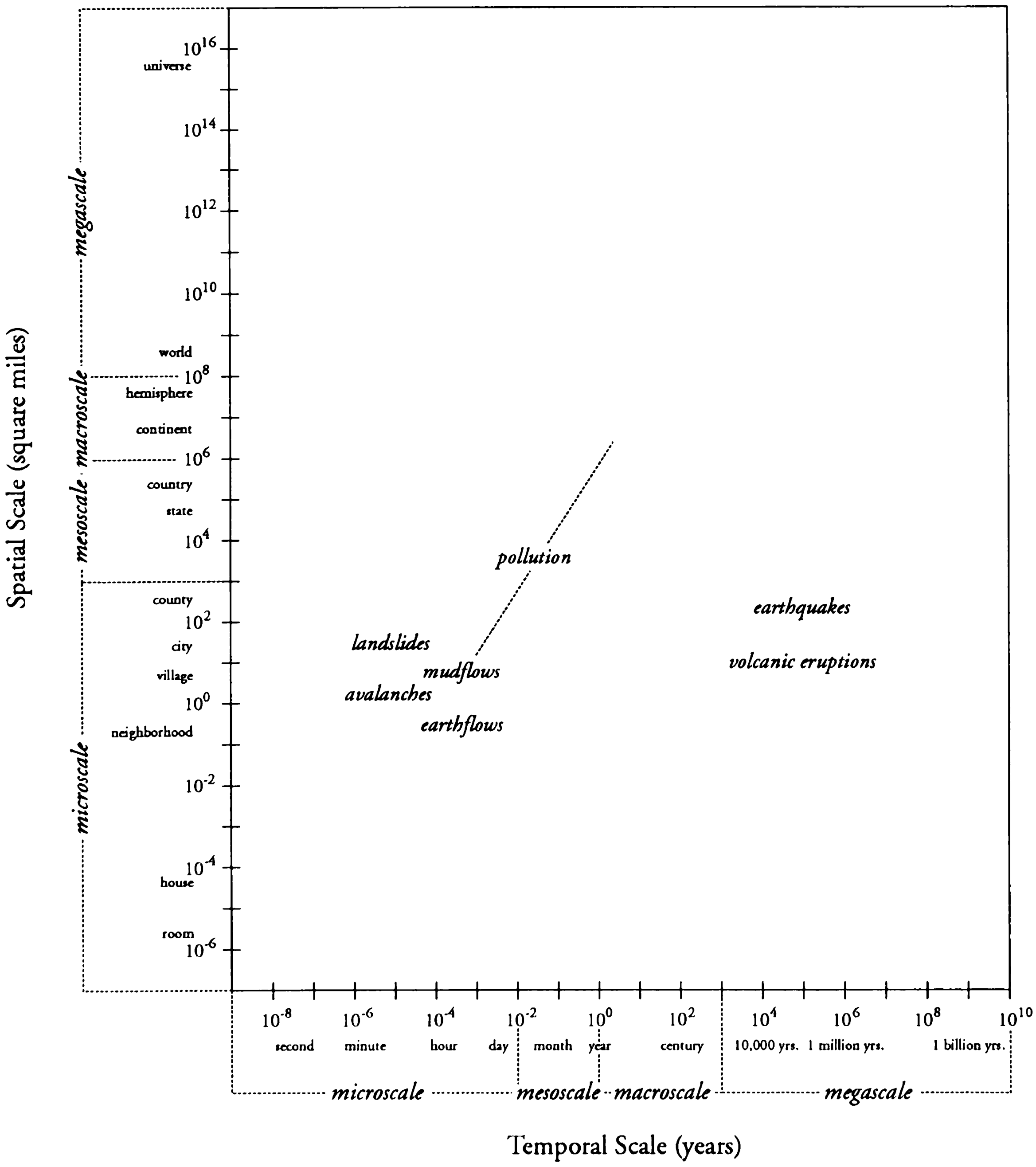


Figure 4.13 Scale Paradigm of Intermittent Volumetric Movements.

Pollution also occurs in the other earth systems, such as the hydrosphere and lithosphere. Like other forms of environmental contamination, water pollution, although a somewhat common occurrence, is difficult, if not impossible, to predict. Generally affecting less area over shorter periods of time than many forms of air pollution, pollution of surface water and ground water by sewage, fertilizers, and chemicals occurs irregularly due to such point and non-point pollution sources as leaching landfills, urban and suburban areas and industrial plants. Hazardous contamination, like the 1989 Exxon Valdez oil spill that dumped over ten million gallons of crude oil in Alaska's Prince William Sound, pollute not only large volumes of water, but also sand and rock along miles of shoreline. Since 1967, over twenty notable oil spills have intermittently occurred throughout the world (Famighetti 1996). Once entered into the water balance system, pollutants may travel to the water table, where the pollutants then follow the flow paths of ground water.

Other examples of volumetric geographic phenomena that occur intermittently are some forms of *mass wasting*, a collective term for the spontaneous downward movement of soil, regolith, and bedrock under the influence of gravity. Although abundant evidence shows that on most slopes at least a small amount of downhill movement is going on continuously, much of this motion is imperceptible (Strahler and Strahler 1984). Rather it is when the regolith exhibits "rapid colonization over large areas triggered by an acute, perhaps unique, event" and slides or flows abruptly causing environmental hazards such as *earthflows*, *mudflows*, *landslides*, and *avalanches* that should be noted (Parker 1993, 626). Each of these phenomena involve the sporadic movement of mass wasting volumes that can vary in both temporal and spatial scale.

Earthflows occur in regions of humid climate and are a mass of water-saturated soil, regolith, or weak shale that moves down a steep slope. Falling within the spatial and temporal microscale domain, an earthflow may affect areas from a few square meters up to several hectares, and usually has a slow flowage rate of a few hours. *Mudflows* consist of the downslope flowage of a mixture of water and mineral fragments, varying in

consistency from a mixture resembling thick viscous concrete to consistencies that are little different than in turbid stream floods. As with earthflows, mudflows occur in micro temporal and spatial scales, but at slightly larger spatial extents such as a village. *Landslides* also occur sporadically and yield perhaps the quickest and largest volumetric movement of all mass wasting phenomena (Strahler and Strahler 1984). Usually occurring in thinly populated mountainous regions, landslides involve the sudden release of millions of cubic meters of rock down a mountainside, such as the 1959 Madison River gorge landslide that formed a debris dam over 200 feet high and contained thirty-five million cubic yards of debris (Strahler and Strahler 1984). Similar to landslides in that they occur within minutes and can cover tens to hundreds of square miles, *avalanches* involve the sudden downward movement of snow. Occurring in alpine environments where climate and snowpack characteristics vary spatially, avalanches are unpredictable due to variations in weather during a season which affect tendencies of the snowpack toward either failure or increased stability (Mock and Kay, 1992).

Some final examples of intermittent volumetric geographic phenomena are *volcanic eruptions* and *earthquakes*. While a singular volcanic eruption or earthquake is interpreted as a continuous volumetric movement at very micro scales, and numerous occurrences of these geologic cataclysms are interpreted with much larger scale frames (both spatially and temporally) as intermittent point phenomena, multiple occurrences of these phenomena *at the same location* viewed over long time frames can be seen as exhibiting intermittent volumetric movement. For example, Mount Rainier, the highest volcano peak in North America's Cascade Range, has erupted numerous times in the past (most recently, just 150 years ago) and geologists warn that it will erupt again anytime within the next ten to 10,000 years. However, given that at least sixty major lahars (flash floods of semi liquid mud, rock, and ice) have flowed down Rainier over the past 10,000 years, volcanologists suggest that the recurrence interval for major debris flows is somewhere between 500 and 1,000 years (Krakauer 1996). Similar interpretations can be applied to the rather unpredictable occurrence of earthquakes at or near the same location or focus such as locations along the renowned San Andreas fault in the western United States. Using micro spatial and mega temporal scale references, the unpredictable seismic activity related to particular earthquake sites and active volcanoes becomes apparent.

Multi-Type Phenomena

Twelve individual classes of movement have been presented as a general framework with which to organize and understand all spatially dynamic phenomena. The classification of geographic movement is exhaustive; with four spatial categories cross referenced with three temporal categories, the matrix allows for all possible forms of geographic motion to be described. Each spatially dynamic geographic phenomenon can be classed into one or more of the twelve unique movement categories. Some geographic phenomena are viewed using a wide array of spatial and/or temporal perspectives, whereby they may fall into more than one movement class. Examples of such multi-type phenomena occurring in the human world include trade and commerce, route services, regional boundary changes, diffusion, and human mobility. Using very small or narrow scale frames in analyzing a person's mobility through space and time yields journey-to-work and personal action space analyses. With this vantage point, human mobility is considered cyclical point movement; the movement occurs repeatedly over a period of hours, days, and weeks. If the time of analysis is lengthened to years, the movements of the same individuals can be interpreted as intermittent, representing residential migration over the course of a life-time.

Tornadoes, hurricanes, earthquakes, and volcanic eruptions are examples of multi-type phenomena in the physical realm. As a geographic movement, volcanic eruptions are classed into three different movement categories: continuous volumetric, intermittent volumetric, and intermittent point. When a volcano erupts, lava, gases, and solid earth fragments flow, as various three-dimensional forms, down its side and through the air and

is considered a continuous volumetric phenomenon. Examination of that same volcano over a much longer time frame of thousands to millions of years describes intermittent volumetric movement; numerous eruptions may have occurred, the periodicity of which are infrequent and largely unpredictable. By changing scales once again, those same volcanic eruptions can be examined with an even broader scope that places them in mega time and space with respect to all other volcanic eruptions across the world. Viewed with this perspective, each eruption is interpreted as a point in space that, once in a while, is active and displays movement.

As human mobility and volcanic eruptions demonstrate, scale can vary in both the temporal and spatial dimensions in interpretations of phenomena and any variation in one or both of these components will change the focus of the geographic inquiry. When the scope of any study is determined, decisions are made about what is to be studied in detail and what is to be left in the background (Hudson 1992), and depending on the point of view of the observer, different analyses of the same phenomenon may take place. Despite the possibility of scalar variations occurring in approaches to particular geographic problems, this classification allows the identification and interpretation of the changes in the spatial location and/or configurations of a phenomenon. Describing the individual components that comprise a geographic phenomenon will lend itself to greater understanding and appreciation of that phenomenon's place in the world with which it interacts.

Chapter 5

CONCLUSIONS

Space is the cornerstone of geography and is the universal characteristic that grounds the discipline. By definition, or at least by one pervasive philosophical viewpoint in geography, a geographic phenomena can be viewed in a spatial context (Lowe and Moryadas 1975). Geographic description and/or explanation often involves examination of a phenomenon over time, thereby revealing patterns and interactions among phenomena on the landscape. Geographic movement involves changes in space and time, which often vary with changes in scale. Movement is an inherent part of virtually all geographic explanation; most geographic concerns, topics, and problems involve consideration of a phenomenon's changing spatial patterns at some level. Many geographic phenomena can be described as spatially dynamic because they do not take place at a particular location and moment frozen in time, but rather "unfold in a variety of sequences" (Knowles 1995, 262). Other phenomena, however, do not exhibit movement through a time period of observation and may be considered spatially static. However, long-term or historical analyses of these phenomena over extended periods of time often reveal a more dynamic spatial nature.

As part of geographic explanation, movement has many associated forms and stimuli, many of which are based on spatial interaction: "Humans are increasing their levels of interaction, in communication, travel, and foreign exchange... People migrate and travel out of curiosity, economic or social need, as a response to environmental change, or because they have been forced to move for other reasons. Physical processes are also expressions of movement - e.g., traveling weather patterns, ocean and wind currents, flowing water, plate tectonics, and volcanism" (Boehm and Petersen 1994, 217). Spatial interaction can be conceptualized as all forms of exchange movement involving people, goods, information,

and/or ideas between two or more places. All human geographic phenomena, regardless of whether they involve individuals, establishments, or settlements, are involved in spatial interaction processes as a necessary part of their overall functions. The four integrating concepts of spatial interaction are often taken into consideration simultaneously in order to provide a "parsimonious" explanation of why place-to-place movement occurs (Lowe and Moryadas 1975, 11). As geographers, we typically investigate particular features of a spatial interaction or process such as why it has occurred or what multiple effects has it imposed on other related phenomena. Process, pattern, and behavior are often separated and distinguished in geography by what moves, why it moves, and how it relates to various well defined subjects of inquiry such as economics, culture, psychology, and human medicine. Geographically, we try to understand the dynamic spatiotemporal patterns and processes of human and physical phenomena as they interact with one another.

Geography's study of phenomena over space and time is neither new or unique. Since the passage from the paradigm of 'geography-as-chorology' in the 1950's, a variety of approaches for studying space-time phenomena has evolved from early works in historical geography demonstrating "geographical change," to autocorrelation, to Hagerstrand's models of diffusion and time geography (Peuquet 1994, 441). Geographers often generalize the interrelationships between time and space by asking "what kinds of order are exhibited by geographical information and on what scale of space and time each operates" (Haggett and Chorley 1967, 20). Greater emphasis has been placed on this approach in current geographical inquiry and research as urban growth, agricultural impacts, and global warming have become critical problems on earth (Peuquet 1996). The need to better understand the effects of human activities on the natural environment by analyzing patterns of change at all geographic scales is now viewed with increasing urgency. For example, in natural resource management within developed nations, the emphasis is shifting from inventory and exploitation toward maintaining the long-term productivity of the environment. This requires interactive space-time analyses at multiple scales as a way of understanding the complex interrelationships of environmental systems.

Recent developments in technology-oriented tools have helped in the examination and analysis of such dimensionally complex geographic problems. Peuquet and Duan (1995) have incorporated spatiotemporal capabilities in their recently developed geographic information system called the Event-based SpatioTemporal Data Model (ESTDM) that will ultimately allow temporal modeling and simulation of geographical processes. Other geographic information systems are currently using Global Circulation Models (GCMs) to study climate and ocean dynamics, as well as global warming. Verification and refinement of these models require sophisticated analysis of large volumes of multidimensional data, particularly the study of change and patterns of change through time over the earth, in the oceans, and through the atmosphere. Related to this research of dynamics in GIS is the development of new computerized techniques for visualization of phenomena as they move in three spatial dimensions over time. Research in this area is of particularly high priority but has only begun to be explored and involves using tools such as regular polytope geometry and object-oriented design to achieve the needed representational schemes specific for volumetric and dynamic geography (Peuquet 1996). Spatial visualization techniques, particularly animation, allow geographers to incorporate change in space and through time and have released cartography from the confines of the two-dimensional page in which it has been "trapped" over the years (DiBiase et al. 1992; Langran 1992, 163). Peuquet (1996) urges that a medium-term (concrete benefits in thirty-five years) priority area for visualization research is to develop a space-time data model that can represent dynamic processes and spatial interactions in an effective manner that includes multiple scales, multiple dimensions, and a diverse range of data types.

The presented classification of geographic movement represents such a conceptual model. Classification, as a descriptive model, is a valuable research tool used in the dissemination and organization of complex information. As a way of comprehending the underlying principles and generic relationships between objects and processes, classification

is a traditional methodological approach used by geographers as a way of providing differentiation in geography (Armand 1965; Haggett and Chorley 1967). Over thirty years ago, Berry (1964) suggested that classification in geography be conceptualized as a matrix, with phenomena categorized in terms of their type of activity, their location, and their time. The classification of movement adopts a similar abstraction; spatially dynamic geographic phenomena are generalized in terms of their temporal and spatial components. The framework presents the conceptualization of how things move and in doing so, presents a description of the geometry of geographic movement. Serving as a movement language that enables one to describe and interpret the changing distribution of phenomena in space and through time, the model accounts for all forms of geographic movement with twelve unique classes. Spatially, the shape a phenomenon exhibits as it moves through three-dimensional space can be interpreted as one of four basic types: point, linear, areal, or volumetric. Movements in space occur in one of three temporal fashions representing the duration and periodicity of the occurrence: continuous, cyclical, or intermittent. The classification, which can be applied on a variety of spatial scales, from local, to international, to global, on a variety of temporal scales, from seconds and minutes, to days and weeks, to various groupings of years, and to a variety of phenomena including physical, human, and human-environmental relations, has utility far reaching to all branches of social sciences and beyond. Analysts from other disciplines such as history, anthropology, and sociology can apply the classification's generalization of space and time to their analyses of varied earth phenomena.

The classification of geographic movement is important at many levels as a vehicle with which to strengthen explanation and understanding of dynamic geographic phenomena. First, by breaking a complex process, event, or observation down into its individual inherent geographic characteristics of space and time, the basic principles associated with these fundamental dynamic properties can be observed and comprehended. Once each spatiotemporal component's contribution to the movement is understood, then conclusions about the relationships between space and time, as well as among other features associated with the phenomenon, can be drawn. For example, if one can relate the movements conceptualized with a bouncing ball (i.e., the object is moving from point to point to point) to the ideas of interaction that is occurring at each of these individual points with the surface of the earth, then one can apply these same fundamental notions about space and time to point-to-point phenomena such as human mobility. By building a foundation that is predicated upon characteristics universal to all geographic phenomena, a more clear understanding of the spatiotemporal interrelationships among phenomena can be gained. For instance, to understand the geography of satellites, one must first comprehend the movements associated with the revolution of the earth about the sun, as well as the rotation of the earth on its own axis. Once these dynamics of the earth can be visualized and conceptualized in terms of space and time, understanding the associated movements of a satellite with respect to the earth is possible, thereby facilitating conclusions as to how and for what purposes this technology is used.

Understanding the fundamental spatiotemporal characteristics of a geographic phenomenon also allows parallels to previously unlinked phenomena to be drawn. In the case of spatial diffusion, the areal spread of phenomena involves the locational transfer of people, things, and information and is signified with some recognizable pattern and organized structure (Lowe and Moryadas 1975). The diffusion of gypsy moth defoliation spreads across a stand in a similar fashion as urban sprawl encroaches land around a metropolitan center. Traditionally, the two phenomena are not compared because geographic understanding of gypsy moth infestations has often been focused on studying the correlations between defoliation and landscape variables such as tree type, climate, and soil composition for predictive and management measures. Urban sprawl studies typically focus on identifying settlement and urbanization patterns for observation and planning practices. However, the dynamic geometry of these two phenomena are similar and parallel conclusions about the movement patterns associated with each can be made. For example, the understanding that features in the landscape such as rivers or mountains may serve as barriers to the movement of defoliation can then be applied to study such 'spillover' abatements in spreads of urbanization.

Finally, and most importantly, the classification's utility extends to the research community where current and future enhancements of computerized techniques dealing with movements associated with geographic phenomena rely on an extensive knowledge of space-time dynamics. Increasing attention is being paid to the integrative changes, activities, and interactions taking place in the human and physical landscapes. Spatiotemporal data are becoming significantly more tangible in research and educational settings, as the means by which we compile, store, analyze, and represent data have produced an explosion of dynamic geographic information. However, many geographic problems are approached, analyzed, described, and explained in very diverse manners. Any modeling of spatially dynamic phenomena should consider the spatiotemporal complexities associated with various, previously unrelated, phenomena. Incorporating the components and nuances important to the understanding of all movements will ensure not only that dynamic features will be handled appropriately for a given studied phenomenon but that the dynamics of other phenomena influential to its movements are adequately accounted for and can easily be incorporated into an analysis. For example, in developing computer applications for effective emergency management procedures related to hurricanes, modeling various space-time configurations related to the phenomenon, such as the changing locations of the storm's eye, the spatial dimensions of the extent or diameter of the storm, as well as the rate and direction of the storm's movement across water and land are of utmost importance. However, one must also consider and integrate into the model the concurrent movements of the earth's atmosphere at or near the storm's eye and path, as the dynamic conditions of the atmosphere most definitely influence the movement of the hurricane. Also important to incorporate into this analysis are the associated movements that interaction of the hurricane on the surface of the earth will cause, such as flooding and evacuation procedures of local residents. An effective and complete emergency management model of hurricanes should therefore account for all the various integrating movements of phenomena interacting with the movement of the hurricane.

Modeling, analyzing, and representing complex phenomena in a computer environment is important for furthering explanation, education, and understanding of complex phenomena and their interactions with one another. Creating a knowledge-based system by which the fundamental properties associated with all geographic movement are synthesized and organized in a convenient manner in which the abstract notions of space and time are easily conceptualized will help this cause. Just as cartographic research on color has defined the significance of various core principles (e.g., saturation, hue, and value) for effective modeling and execution of various cartographic applications, the identification of important and distinctive spatial and temporal characteristics of all spatially dynamic phenomena will provide researchers, educators, and the like a foundation with which to strengthen geographic description and explanation. Summarizing the conceptualization of movement, the classification serves this purpose well by functioning as an aid in the description and comprehension of what is happening in a geographical context and as a method to relate various geographic phenomena based on the form taken as they occur through space and time. Understanding geographic movement by interpreting the complex spatial and temporal characteristics associated with various geographic phenomena may lead to the consciousness of ideas, interrelationships, and conclusions about spatially dynamic phenomena within the larger realm of geography.

LIST OF REFERENCES

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Abler, Ronald, John S. Adams, and Peter Gould. 1971. *Spatial Organization: The Geographer's View of the World.* Englewood Cliffs, New Jersey: Prentice-Hall.

Adams, Paul C. 1995. A Reconsideration of Personal Boundaries in Space-Time. *Annals of the Association of American Geographers* 85(2):267-285.

Allen, James F. 1984. Towards a General Theory of Action and Time. *Artificial Intelligence* 23(2):123-154.

Allen, James P., and Eugene Turner. 1996. Spatial Patterns of Immigrant Assimilation. *Professional Geographer* 48(2):140-155.

Anderson, T. Lougenia. 1982. Modeling Time at the Conceptual Level. In *Improving Database Usability and Responsiveness*, ed. Peter Scheuermann, 273-297. New York: Academic Press.

Armand, David L. 1965. The Logic of Geographical Classifications and Regionalization Schemes. *Soviet Geography: Review and Translation* 6(9):20-38.

Baker, Earl J. 1995. Public Response to Hurricane Probability Forecasts. *Professional Geographer* 47(2):137-147.

Baker, William L. 1989. A Review of Models of Landscape Change. *Landscape Ecology* 2(2):111-133.

Barrera, Renato, Andrew Frank, and Khaled Al-Taha. 1991. *Temporal Relations in Geographic Information Systems: A Workshop at the University of Maine, Orono, October 12-13, 1990.* Technical Paper, 91-94. Orono, Maine: National Center for Geographic Information and Analysis.

Bascom, Jonathan. 1993. The Peasant Economy of Refugee Resettlement in Eastern Sudan. *Annals of the Association of American Geographers* 83(2):320-346.

Beach, Timothy. 1994. The Fate of Eroded Soil: Sediment Sinks and Sediment Budgets of Agrarian Landscapes in Southern Minnesota, 1851-1988. *Annals of the Association of American Geographers* 84(1):5-28.

Behr, Michelle, and Patricia Gober. 1982. When a Residence is not a House: Examining Residence-Based Migration Definitions. *Professional Geographer* 34(2):178-184.

Berry, Brian J. L. 1958. A Note Concerning Methods of Classification. *Annals of the Association of American Geographers* 48:300-303.

Berry, Brian J. L. 1964. Approaches to Regional Analysis: A Synthesis. *Annals of the Association of American Geographers* 54(1):2-11.

Berry, Brian J. L. 1972. The Goals of City Classification. Introduction in *City Classification Handbook: Methods and Applications,* ed. Brian J. L. Berry with the assistance of Katherine B. Smith, 1-8. New York: John Wiley and Sons.

Berry, Brian J. L. 1993. Transnational Urbanward Migration, 1830-1980. *Annals of the Association of American Geographers* 83(3):389-405.

Bertin, Jacques. 1983. *Semiology of Graphics: Diagrams, Networks, Maps.* Translated by William J. Berg. Madison, Wisconsin: University of Wisconsin Press.

Bird, James H. 1989. *The Changing Worlds of Geography, A Critical Guide to Concepts and Methods.* New York: Oxford University Press.

Blaut, James M. 1972. Space and Process. Chap. 2 in *The Conceptual Revolution*, ed. Wayne K. D. Davies, 42-51. London: University of London Press.

Blewett, William L., and Harold A. Winters. 1995. The Importance of Glaciofluvial Features Within Michigan's Port Huron Moraine. *Annals of the Association of American Geographers* 85(2):306-319.

Boehm, Richard G., and James F. Petersen. 1994. An Elaboration of the Fundamental Themes in Geography. *Social Education* 58(4):211-218.

Bradshaw, Michael J., and Nicholas J. Lynn. 1994. After the Soviet Union: The Post-Soviet States in the World System. *Professional Geographer* 46(4):439-449.

Buchanan, Janis T., and William Acevedo. 1996. Studying Urban Sprawl Using a Temporal Database. *Geo Info Systems* 6(7):42-44, 46-47.

Bunge, William. 1966. *Theoretical Geography.* Lund Studies in Geography Ser. C. General and Mathematical Geography No. 1. Lund, Sweden: C. W. K. Gleerup.

Business Geographics. 1996. BG News. 4(8):12-14, 16-17.

Campbell, David J., and Jennifer M. Olson. 1991. *Framework for Environment and Development: The Kite.* Occasional Paper No. 10. East Lansing, Michigan: Center for Advanced Study of International Development.

Carlile, David W., John R. Skalski, John E. Batker, John M. Thomas, and V. I. Cullinan. 1989. Determination of Ecological Scale. *Landscape Ecology* 2(4):203-213.

Carlstein, Tommy. 1978. Innovation, Time Allocation and Time-Space Packing. Chap. 8 in *Timing Space and Spacing Time, Vol. 2: Human Activity and Time Geography*, ed. Tommy Carlstein, Don Parkes, and Nigel Thrift, 146-161. New York: John Wiley & Sons.

Casetti, Emilio. 1993. Spatial Analysis: Perspectives and Prospects. *Urban Geography* 14(6):526-537.

Chorley, Richard J. 1968. Geography and Analog Theory. Chap. 4 in *Spatial Analysis, A Reader in Statistical Geography*, ed. Brian J. L. Berry and Duane F. Marble, 42-52. Englewood Cliffs, New Jersey: Prentice-Hall.

Clark, Terry N. 1972. Urban Typologies and Political Output. Chap. 5 in *City Classification Handbook: Methods and Applications*, ed. Brian J. L. Berry with the assistance of Katherine B. Smith, 152-178. New York: John Wiley and Sons.

Comrie, Andrew C. 1994. Tracking Ozone: Air-Mass Trajectories and Pollutant Source Regions Influencing Ozone in Pennsylvania Forests. *Annals of the Association of American Geographers* 84(4):635-651.

Critchfield, Howard J. 1983. *General Climatology*. 4th ed. Englewood Cliffs, New Jersey: Prentice-Hall.

Delcourt, Hazel R., and Paul A. Delcourt. 1988. Quaternary Landscape Ecology: Relevant Scales in Space and Time. *Landscape Ecology* 2(1):23-44.

DiBiase, David, Alan M. MacEachren, John B. Krygier, and Catherine Reeves. 1992. Animation and the Role of Map Design in Scientific Visualization. *Cartography and Geographic Information Systems* 19(4):201-214, 265-266.

Dobson, Jerome E. 1992. Spatial Logic in Paleogeography and the Explanation of Continental Drift. *Annals of the Association of American Geographers* 82(2):187-206.

Doob, Leonard W. 1978. Time: Cultural and Social Anthropological Aspects. Chap. 5 in *Timing Space and Spacing Time, Vol. 1: Making Sense of Time*, ed. Tommy Carlstein, Don Parkes, and Nigel Thrift, 56-65. New York: John Wiley and Sons.

Dorling, Daniel. 1992. Stretching Space and Splicing Time: From Cartographic Animation to Interactive Visualization. *Cartography and Geographic Information Systems* 19(4):215-227.

Dubin, Robert. 1969. *Theory Building*. New York: The Free Press.

Dyer, James M. 1994. Implications of Habitat Fragmentation on Climate Change-Induced Forest Migration. *Professional Geographer* 46(4):449-459.

Earle, Carville. 1992. Pioneers of Providence: The Anglo-American Experience, 1492-1792. *Annals of the Association of American Geographers* 82(3):478-499.

Falah, Ghazi. 1996. The 1948 Israeli-Palestinian War and its Aftermath: The Transformation and De-Signification of Palestine's Cultural Landscape. *Annals of the Association of American Geographers* 86(2):256-285.

Famighetti, Robert. 1996. *The World Almanac and Book of Facts, 1996*. Mahwah, New Jersey: Funk and Wagnalls Corporation.

Forer, P. C., and Helen Kivell. 1981. Space-Time Budgets, Public Transport, and Spatial Choice. *Environment and Planning* 13:497-509.

Galloway, J. H. 1996. Botany in the Service of Empire: The Barbados Cane-Breeding Program and the Revival of the Caribbean Sugar Industry, 1880s-1930s. *Annals of the Association of American Geographers* 86(4):682-706.

Gares, Paul A., and Karl F. Nordstrom. 1995. A Cyclic Model of Foredune Blowout Evaluation for a Leeward Coast: Island Beach, New Jersey. *Annals of the Association of American Geographers* 85(1):1-20.

Garner, Barry J. 1967. Models of Urban Geography and Settlement Location. In *Models in Geography*, ed. Richard J. Chorley and Peter Haggett, 303-360. London: Methuen.

Gilmour, John S. L., and Stuart M. Walters. 1964. Philosophy and Classification. *Vistas in Botany* 4:1-22.

Gleick, James. 1987. *Chaos: Making a New Science.* New York: Viking Press.

Golledge, Reginald G., Valerie Dougherty, and Scott Bell. 1995. Acquiring Spatial Knowledge: Survey Versus Route-Based Knowledge in Unfamiliar Environments. *Annals of the Association of American Geographers* 85(1):134-158.

Golley, Frank B. 1989. A Proper Scale. *Landscape Ecology* 2(2):71-72.

Goodchild, Michael F. 1992. Analysis. Chap. 7 in *Geography's Inner Worlds, Pervasive Themes in Contemporary American Geography*, ed. Ronald F. Abler, Melvin G. Marcus, and Judy M. Olson, 138-162. New Brunswick, New Jersey: Rutgers University Press.

Gould, William T. S., and R. Mansell Prothero. 1973. *Space and Time Dimensions in the Study of Population Mobility in Tropical Africa.* African Population Mobility Project Working Paper No. 1. Liverpool, United Kingdom: University of Liverpool.

Graf, William L., and Patricia Gober. 1992. Movements, Cycles, and Systems. Chap. 11 in *Geography's Inner Worlds, Pervasive Themes in Contemporary American Geography*, ed. Ronald F. Abler, Melvin G. Marcus, and Judy M. Olson, 234-254. New Brunswick, New Jersey: Rutgers University Press.

Graff, Thomas O., and Dub Ashton. 1993. Spatial Diffusion of Wal-Mart: Contagious and Reverse Hierarchical Elements. *Professional Geographer* 46(1):19-29.

Green, Kass, and Brian Cosentino. 1996. Using Satellite Imagery to Detect and Monitor Forest Change. *Geo Info Systems* 6(2):22, 24-26, 28-30.

Griffith, Daniel A., and Anthony C. Lea. 1983. Introduction. In *Evolving Geographical Structures, Mathematical Models and Theories for Space-Time Processes.* NATO Advanced Science Institutes Series D: Behavioral and Social Sciences, No. 15, ed. Daniel A. Griffith and Anthony C. Lea, 1-8. The Hague, Netherlands: Martines Nijhoff.

Grigg, David. 1965. The Logic of Regional Systems. *Annals of the Association of American Geographers* 55:465-491.

Guralnik, David B. 1984. *Webster's New World Dictionary of the American Language.* 2nd college ed. New York: Simon and Schuster.

Haggett, Peter. 1967. Network Models in Geography. Chap. 15 in *Models in Geography*, ed. Richard J. Chorley and Peter Haggett, 609-668. London: Methuen.

Haggett, Peter. 1975. Simple Epidemics in Human Populations: Some Geographical Aspects of the Hamer-Soper Diffusion Models. Chap. 18 in *Processes in Physical and Human Geography*, ed. Ronald Peel, Michael Chrisholm, and Peter Haggett, 373-391. London: Heinemann Educational Books.

Haggett, Peter. 1978. Regional and Local Components in Elementary Space-Time Models. Chap. 2 in *Timing Space and Spacing Time, Vol. 3: Time and Regional Dynamics*, ed. Tommy Carlstein, Don Parkes, and Nigel Thrift, 19-34. New York: John Wiley & Sons.

Haggett, Peter. 1979. *Geography, A Modern Synthesis.* 3rd. ed. New York: Harper and Row.

Haggett, Peter. 1990. *The Geographer's Art.* Cambridge, Massachusetts: Basil Blackwell.

Haggett, Peter, and Richard J. Chorley. 1967. Models, Paradigms and the New Geography. Chap. 1 in *Models in Geography*, ed. Richard J. Chorley and Peter Haggett, 19-41. London: Methuen.

Haggett, Peter, and Richard J. Chorley. 1969. *Network Analysis in Geography.* London: Edward Arnold Publishers Ltd.

Hall, Forrest G., Donald E. Strebel, and Piers J. Sellers. 1988. Linking Knowledge Among Spatial and Temporal Scales: Vegetation, Atmosphere, Climate and Remote Sensing. *Landscape Ecology* 2(1):3-22.

Hardwick, Susan Wiley, and Donald G. Holtgrieve. 1990. *Patterns on our Planet: Concepts and Themes in Geography.* New York: Macmillan.

Hardwick, Susan Wiley, and Donald G. Holtgrieve. 1996. *Geography for Educators: Standards, Themes, and Concepts.* Upper Saddle River, New Jersey: Prentice Hall.

Harner, John P. 1995. Continuity Amidst Change: Undocumented Mexican Migration to Arizona. *Professional Geographer* 47(4):399-411.

Hartshorne, Richard. 1959. *Perspective on the Nature of Geography.* Chicago: Rand McNally.

Harvey, David. 1969. *Explanation in Geography.* London: Edward Arnold.

Hawking, Stephen W. 1988. *A Brief History of Time: From the Big Bang to Black Holes.* New York: Bantam Books.

Hayles, N. Katherine. 1991. Complex Dynamics in Literature and Science. Introduction in *Chaos and Order, Complex Dynamics in Literature and Science,* ed. N. Katherine Hayles, 1-33. Chicago: The University of Chicago Press.

Heirich, Max. 1964. The Use of Time in the Study of Social Change. *American Sociological Review* 29(3):386-397.

Hill, A. David. 1989. Rediscovering Geography: It's Five Fundamental Themes. *National Association of Secondary School Principals* 73(521):1-7.

Holly, Brian P. 1978. The Problem of Scale in Time-Space Research. Chap. 1 in *Timing Space and Spacing Time, Vol. 3: Time and Regional Dynamics*, ed. Tommy Carlstein, Don Parkes, and Nigel Thrift, 5-18. New York: John Wiley & Sons.

Hudson, John C. 1972. *Geographical Diffusion Theory*, Studies in Geography, No. 19. Evanston, Illinois: Northwestern University.

Hudson, John C. 1988. North American Origins of Middlewestern Frontier Populations. *Annals of the Association of American Geographers* 78(3):395-413.

Hudson, John C. 1992. Scale in Space and Time. Chap. 13 in *Geography's Inner Worlds, Pervasive Themes in Contemporary American Geography*, ed. Ronald F. Abler, Melvin G. Marcus, and Judy M. Olson, 280-297. New Brunswick, New Jersey: Rutgers University Press.

Ivy, Russell L. 1995. The Restructuring of Air Transport Linkages in the New Empire. *Professional Geographer* 47(3):280-288.

Jackson, Nancy L. 1995. Wind and Waves: Influence of Local and Non-Local Waves on Mesoscale Beach Behavior in Estuarine Environments. *Annals of the Association of American Geographers* 85(1):21-37.

Jakle, John A., Stanley Brunn, and Curtis C. Roseman. 1976. *Human Spatial Behavior: A Social Geography*. North Scituate, Massachusetts: Duxbury Press.

Johnston, Ronald J. 1968. Choice in Classification: The Subjectivity of Objective Methods. *Annals of the Association of American Geographers* 58(3):575-589.

Johnston, Ronald J. 1970. Grouping and Regionalizing: Some Methodological and Technical Observations. *Economic Geography* 46(2 Supplement):293-305.

Johnston, Ronald J. 1986. *Philosophy and Human Geography: An Introduction to Contemporary Approaches*. Baltimore, Maryland: Edward Arnold.

Johnston, Ronald J. 1991. *Geography and Geographers: Anglo-American Human Geography Since 1945*. New York: Edward Arnold.

Johnston-Anumonwo, Ibipo. 1992. The Influence of Household Type on Gender Differences in Work Trip Distance. *Professional Geographer* 44(2):161-169.

Joint Committee on Geographic Education. 1984. *Guidelines for Geographic Education*. The Association of American Geographers and the National Council for Geographic Education.

Jordan, Lawrie E. III. 1996. High-Resolution Imagery for Business Decision Support. *Geo Info Systems* (Supplement):24-27.

Jordan, Terry G., and Lester Rowntree. 1986. *The Human Mosaic, A Thematic Introduction to Cultural Geography*. 4th ed. New York: Harper and Row, Publishers.

Kaplan, Abraham. 1964. *The Conduct of Inquiry: Methodology for Behavioral Science*. San Francisco: Chandler Publishing.

Kellerman, Aharon. 1989. *Time, Space, and Society: Geographical Societal Perspectives.* Netherlands: Kluwer Academic Publishers.

Kelmelis, John A. 1991. *Time and Space in Geographic Information: Toward a Four-Dimensional Spatio-Temporal Data Model.* Ph.D. diss., Pennsylvania State University.

Kennedy, Frances H. 1990. *The Civil War Battlefield Guide.* Boston, Massachusetts: Houghton Mifflin.

Knapp, Paul A., and Peter. T. Soule. 1996. Vegetation Change and the Role of Atmospheric CO_2 Enrichment on a Relict Site in Central Oregon: 1960-1994. *Annals of the Association of American Geographers* 86(3):387-411.

Knight, Cheryl S. 1994. *The Five Fundamental Themes of Geography, Geography Across the Curriculum: A Teacher's Activity Guide (Grades K-5).* Boone, North Carolina: Parkway Publishers.

Knowles, Anne K. 1995. Immigration Trajectories Through the Rural-Industrial Transition in Wales and the United States, 1795-1850. *Annals of the Association of American Geographers* 85(2):246-266.

Krakauer, Jon. 1996. Geologists Worry About Dangers of Living 'Under the Volcano.' *Smithsonian* 27(4):33-40.

Langran, Gail. 1989a. A Review of Temporal Database Research and its Use in GIS Applications. *International Journal of Geographical Information Systems* 3(3):215-232.

Langran, Gail. 1989b. *Time in Geographic Information Systems.* Ph. D. diss., University of Washington.

Langran, Gail. 1992. *Time in Geographic Information Systems.* Philadelphia: Taylor & Francis.

Leach, Edmund R. 1961. Two Essays Concerning the Symbolic Representation of Time. Chap. 6 in *Rethinking Anthropology.* London School of Economics Monographs on Social Anthropology No. 22, ed. Edmund R. Leach, 124-136. London: The Athlone Press.

Lee, Dong Ok. 1995. Koreatown and Korean Small Firms in Los Angeles: Locating in the Ethnic Neighborhoods. *Professional Geographer* 47(2):184-195.

Lee, Jeffrey A., and Vatche P. Tchakarian. 1995. Magnitude and Frequency of Blowing Dust in the Southern High Plains of the United States, 1947-1989. *Annals of the Association of American Geographers* 85(4):684-693.

Lee, Jay, Ligang Chen, and Shih-lung Shaw. 1994. A Method for the Exploratory Analysis of Airline Networks. *Professional Geographer* 46(4):468-477.

Lewis, Peter W. 1965. Three Related Problems in the Formulation of Laws in Geography. *Professional Geographer* 17(5):24-27.

Lightman, Alan. 1993. *Einstein's Dreams.* New York: Panthem Books.

Lloyd, Robert, David Patton, and Rex Cammack. 1996. Basic-Level Geographic Categories. *Professional Geographer* 48(2):181-194.

Lowe, John C., and S. Moryadas. 1975. *The Geography of Movement.* Prospect Heights, Illinois: Waveland Press.

Lucas, John R. 1973. *A Treatise on Time and Space.* London: Methuen.

MacEachren, Alan M. 1992. Visualizing Uncertain Information. *Cartographic Perspectives* 13(Fall):10-19.

MacEachren, Alan M., Barbara J. Buttenfield, James B. Campbell, David W. DiBiase, and Mark Monmonier. 1992. Visualization. Chap. 6 in *Geography's Inner Worlds, Pervasive Themes in Contemporary American Geography*, ed. Ronald F. Abler, Melvin G. Marcus, and Judy M. Olson, 99-137. New Brunswick, New Jersey: Rutgers University Press.

Manson, Gary A., and Richard E. Groop. 1996. Ebbs and Flows in Recent U. S. Interstate Migration. *Professional Geographer* 48(2):156-166.

Martin, David. 1991. *Geographic Information Systems and Their Socioeconomic Applications.* New York: Routledge.

Martin, Ron L., Nigel J. Thrift, and Robert J. Bennett. 1978. Introduction. In *Towards the Dynamic Analysis of Spatial Systems*, ed. Ron L. Martin, Nigel J. Thrift, and Robert J. Bennett, 1-6. United Kingdom: Pion.

Marwick, Arthur. 1984. *The Nature of History.* New York: Garland Publishing.

McDermott, Drew. 1982. A Temporal Logic for Reasoning About Processes and Plans. *Cognitive Science* 6(2):101-155.

McHugh, Kevin E., Timothy D. Hogan, and Stephen K. Happel. 1995. Multiple Residence and Cyclical Migration: A Life Course Perspective. *Professional Geographer* 47(3):251-267.

McHugh, Kevin E., and Robert C. Mings. 1996. The Circle of Migration: Attachment to Place in Aging. *Annals of the Association of American Geographers* 86(3):530-550.

McPherson, James M. 1988. *Battle Cry of Freedom: The Civil War Era.* New York: Oxford University Press.

Medley, Kimberly E., Mark J. McDonnell, and Steward T. A. Pickett. 1995. Forest-Landscape Structure Along an Urban-To-Rural Gradient. *Professional Geographer* 47(2):159-168.

Meentemeyer, Vernon. 1989. Geographical Perspectives of Space, Time, and Scale. *Landscape Ecology* 3(3&4):163-173.

Meyer, William B., Derek Gregory, Billie L. Turner II, and Patricia F. McDowell. 1992. The Local Global Continuum. Chap. 2 in *Geography's Inner Worlds, Pervasive Themes in Contemporary American Geography*, ed. Ron F. Abler, Melvin G. Marcus, and Judy M. Olson, 255-279. New Brunswick, New Jersey: Rutgers University Press.

Mitchelson, Ronald L., and James O. Wheeler. 1994. The Flow of Information in a Global Economy: The Role of the American Urban System in 1990. *Annals of the Association of American Geographers* 84(1):87-107.

Mitchneck, Beth, and David Plane. 1995. Migration Patterns During a Period of Political and Economic Shocks in the Former Soviet Union: A Case Study of Yaroslavl' Oblast. *Professional Geographer* 47(1):17-30.

Mock, Cary J., and Paul. A. Kay. 1992. Avalanche Climatology of the Western United States, with an Emphasis on Alta, Utah. *Professional Geographer* 44(3):307-318.

Moore, Tyrel G. 1994. Core-Periphery Models, Regional Planning Theory, and Appalachian Development. *Professional Geographer* 46(3):316-331.

Moran, Warren. 1993. The Wine Appellation as Territory in France and California. *Annals of the Association of American Geographers* 83(4):694-717.

Morrill, Richard L. 1968. Waves of Spatial Diffusion. *Journal of Regional Science* 8(1):118.

Morrill, Richard L. 1978. Geography as Spatial Interaction. In *A Man for all Regions: The Contributions of Edward L. Ullman to Geography.* Papers of the Fourth Carolina Geographical Symposium, Studies in Geography No. 11, ed. John D. Eyre, 16-29. Chapel Hill, North Carolina: University of North Carolina.

Morse, Steans A. 1996. Phenomena, Comment and Notes. *Smithsonian* 27(1):26, 28-29.

Nedobity, Wolfgang. 1986. Classification, Artificial Intelligence and Cognitive Psychology. In *Classification as a Tool of Research.* Proceedings of the 9th Annual Meeting of the Classification Society, ed. Wolfgang Gaul and Martin Schader, 345-352. New York: Elsevier Science.

Orme, John E. 1978. Time: Psychological Aspects. Chap. 6 in *Timing Space and Spacing Time, Vol. 1: Making Sense of Time*, ed. Tommy Carlstein, Don Parkes, and Nigel Thrift, 66-75. New York: John Wiley and Sons.

Parker, Albert J. 1993. Structural Variation and Dynamics of Lodgepole Pine Forests in Lassen Volcanic National Park, California. *Annals of the Association of American Geographers* 83(4):613-629.

Parkes, Don, and Nigel Thrift. 1980. *Times, Spaces, and Places: A Chronogeographic Perspective.* New York: John Wiley and Sons.

Patton, David K. 1997. The Effects of Prior Knowledge on the Learning of Categories of Maps. *Professional Geographer* 49(1):126-136.

Peuquet, Donna J. 1977. *Raster Processing of Spatial Data in Geographic Information Systems.* Ph.D. diss., State University of New York (SUNY) at Buffalo.

Peuquet, Donna J. 1984. A Conceptual Framework and Comparison of Spatial Data Models. *Cartographica* 21(4):66-113.

Peuquet, Donna J. 1994. It's About Time: A Conceptual Framework for the Representation of Temporal Dynamics in Geographic Information Systems. *Annals of the Association of American Geographers* 84(3):441-461.

Peuquet, Donna J. 1996. Extensions to Geographic Representation. Paper presented as part of the *University Consortium for Geographic Information Science (UCGIS) Virtual Seminar discussion.* [Online] Available http://www.ncgia.ucsb.edu/other/ucgis/extensions.html.

Peuquet, Donna J., and Niu Duan. 1995. An Event-Based Spatio-Temporal Data Model (ESTDM) for Temporal Analysis of Geographic Data. *International Journal of Geographical Information Systems* 9(1):7-24.

Phillips, Jonathan D. 1993. Biophysical Feedbacks and the Risks of Desertification. *Annals of the Association of American Geographers* 83(4):630-640.

Pond, Doris. 1992. Gypsy on the Move. *American Forests* 98(3&4):21-24, 65.

Pope, Gregory A., Ronald I. Dorn, and John C. Dixon. 1995. A New Conceptual Model for Understanding Geographical Variations in Weathering. *Annals of the Association of American Geographers* 85(1):38-64.

Porush, David. 1991. Fictions as Dissipative Structures: Prigogine's Theory and Postmodernism's Roadshow. Chap. 3 in *Chaos and Order, Complex Dynamics in Literature and Science,* ed. N. Katherine Hayles, 54-84. Chicago: The University of Chicago Press.

Pred, Allan. 1977. The Choreography of Existence: Comments on Hagerstrand's Time-Geography and its Usefulness. *Economic Geography* 53(2):207-221.

Prince, Hugh. 1978. Time and Historical Geography. Chap. 2 in *Timing Space and Spacing Time, Vol. 1: Making Sense of Time,* ed. Tommy Carlstein, Don Parkes, and Nigel Thrift, 17-37. New York: John Wiley and Sons.

Raphael, Marilyn, and Gerald Mills. 1996. The Role of Mid-Latitude Pacific Cyclones in the Winter Precipitation of California. *Professional Geographer* 48(3):251-262.

Rees, Philip H. 1972. Problems of Classifying Subareas Within Cities. Chap. 10 in *City Classification Handbook: Methods and Applications,* ed. Brian J. L. Berry with the assistance of Katherine B. Smith, 265-330. New York: John Wiley and Sons.

Rescher, Nicholas, and Alasdair Urquhart. 1971. *Temporal Logic.* New York: Springer-Verlag.

Robinson, Roger. 1976. *Ways to Move, The Geography of Networks and Accessibility.* New York: Cambridge University Press.

Rollins, William H. 1995. Whose Landscape? Technology, Fascism, and Environmentalism on the National Socialist Autobahn. *Annals of the Association of American Geographers* 85(3):494-520.

Roseman, Curtis C. 1971. Migration as a Spatial and Temporal Process. *Annals of the Association of American Geographers* 61(3):589-598.

Roseman, Curtis C. 1977. *Changing Migration Patterns Within the United States.* Resource Papers for College Geography No. 77-2. Washington, DC: Association of American Geographers.

Roseman, Curtis C. 1992. Cyclical and Polygonal Migration in a Western Context. In *Community, Society, and Migration: Noneconomic Migration in America*, ed. Patrick C. Jobes, William F. Stinner, and John M. Wardwell, 33-45. Lanham, Maryland: University Press of America.

Schlegel, Richard. 1968. *Time and the Physical World.* New York: Dover Publications.

Shannon, Gary W., and Gerald F. Pyle. 1989. The Origin and Diffusion of Aids: A View from Medical Geography. *Annals of the Association of American Geographers* 79(1):124.

Sinton, David F. 1978. The Inherent Structure of Information as a Constraint to Analysis: Mapped Thematic Data as a Case Study. In *Harvard Papers in Geographic Information Systems*, vol. 7, ed. Geoffrey Dutton, 1-17. Redding, Massachusetts: Wesley Addison.

Soreide, Nancy. 1996. *What is an El Nino?* [Online] Available http://www.pmel.noaa.govhoga-tao/el-nino-story.html, U. S. Dept. of Commerce.

Stewart, Dona. J. 1996. Cities in the Desert: The Egyptian New-Town Program. *Annals of the Association of American Geographers* 86(3):459-480.

Stolle, Hans J. 1987. Michigan Tornadoes: 1930-1969 and 1970-1980. *East Lakes Geographer* 22:88-102.

Strahler, Arthur N., and Alan H. Strahler. 1984. *Elements of Physical Geography.* 3rd ed. New York: John Wiley and Sons.

Sugiura, Yoshio. 1993. Spatial Diffusion of Japanese Electric Power Companies, 1887-1906: A Discrete Choice Modeling. *Annals of the Association of American Geographers* 83(4):641-655.

Thrift, Nigel. 1977. *An Introduction to Time Geography.* Concepts and Techniques in Modern Geography No. 13. Norwich, United Kingdom: Geo Abstracts.

Thurber, Dale K., William R. McClain, and Robert C. Whitmore. 1994. Indirect Effects of Gypsy Moth Defoliation on Nest Predation. *The Journal of Wildlife Management* 58(3):493-500.

Tinline, Rowland. 1972. *A Simulation Study of the 1967-8 Foot-and-Mouth Epizootic in Great Britain.* Ph.D. diss., University of Bristol.

Tobler, Waldo. 1988. Resolution, Resampling, and all that. Chap. in *Building Databases for Global Science*, ed. Helen Mounsey and Roger Tomlinson, 129-137. Philadelphia: Taylor & Francis.

Tuan, Yi-Fu. 1978. Space, Time, Place: A Humanistic Frame. Chap. 1 in *Timing Space and Spacing Time, Vol. 1: Making Sense of Time*, ed. Tommy Carlstein, Don Parkes, and Nigel Thrift, 7-16. New York: John Wiley and Sons.

Turner, Monica G. 1990. Spatial and Temporal Analysis of Landscape Patterns. *Landscape Ecology* 4(1):21-30.

Turner, Monica G., Virginia H. Dale, and Robert H. Gardner. 1989. Predicting Across Scales: Theory Development and Testing. *Landscape Ecology* 3(3&4):245-252.

Ullman, Edward L. 1956. The Role of Transportation and the Bases for Interaction. In *Man's Role in Changing the Face of the Earth*, ed. William L. Thomas Jr., 862-880. Chicago: University of Chicago Press.

US Census Bureau. 1997. *TIGER: The Coast to Coast Digital Map Database!* [Online] Available http://www.census.gov/geo/www/tiger/.

Vandsemb, Berit H. 1995. The Place of Narrative in the Study of Third World Migration: The Case of Spontaneous Rural Migration in Sri Lanka. *Professional Geographer* 47(4):411-425.

Vasiliev, Irinia. 1993. *Categorizing the Cartographic Representation of Time.* Geneseo, New York: State University of New York at Geneseo. Photocopied.

Veeck, Gregory, Li Zhou, and Gao Ling. 1995. Terrace Construction and Productivity on Loessal Soils in Zhongyang County, Shanxi Province, PRC. *Annals of the Association of American Geographers* 85(3):450-467.

Weibel, Robert. 1995. Introduction: Map Generalization in the Context of Digital Systems. *Cartography and Geographic Information Systems* 22(4):259-263.

Weissert, Thomas P. 1991. Representation and Bifurcation: Borges's Garden of Chaos Dynamics. Chap. 10 in *Chaos and Order, Complex Dynamics in Literature and Science,* ed. N. Katherine Hayles, 223-243. Chicago: The University of Chicago Press.

Wheeler, James O., and Ronald L. Mitchelson. 1989. Information Flows Among Major Metropolitan Areas in the United States. *Annals of the Association of American Geographers* 79(4):523-543.

Willmott, Cort J., and Gary L. Gaile. 1992. Modeling. Chap. 8 in *Geography's Inner Worlds, Pervasive Themes in Contemporary American Geography*, ed. Ronald F. Abler, Melvin G. Marcus, and Judy M. Olson, 163-186. New Brunswick, New Jersey: Rutgers University Press.

Wilson, James L. 1993. Mapping the Geographical Diffusion of a Finnish Smallpox Epidemic from Historical Population Records. *Professional Geographer* 45(3):276-286.

Winkler, Julie A. 1992. Regional Patterns of the Diurnal Properties of Heavy Hourly Precipitation. *Professional Geographer* 44(2):127-146.

Wolch, Jennifer R., Afsaneh Rahimian, and Paul Koegel. 1993. Daily and Periodic Mobility Patterns of the Urban Homeless. *Professional Geographer* 45(2):154-169.

Woltemade, Christopher J. 1994. Form and Process: Fluvial Geomorphology and Flood-Flow Interaction, Grant River, Wisconsin. *Annals of the Association of American Geographers* 84(3):462-479.

Wood, William B. 1994. Forced Migration: Local Conflicts and International Dilemmas. *Annals of the Association of American Geographers* 84(4):607-634.

Zweifler, Mark O., Michael A. Gold, and Robert N. Thomas. 1994. Land Use Evolution in Hill Regions of the Dominican Republic. *Professional Geographer* 46(1):39-53.