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THE APPLICATION OF GEOGRAPHIC INFORMATION SYSTEMS (GIS) TO INTERNATIONAL STUDIES

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INTRODUCTION

After a period when international relations scholars essentially ignored the impact of geographical and geopolitical factors in their analyses, the last decade has seen an increasing attempt to "bring geography back in" to international studies (Starr, 1991). Studies of the diffusion of behavioral phenomena as well as the investigation of the relationships between proximity, contiguity, location and territory to international interactions, have burgeoned.[1] These activities by students of international relations have paralleled those of geographers who are focusing on a "new geopolitics" based on the possibilities that the geopolitical environment provide to human decision makers (e.g., see O'Loughlin and Anselin, 1992). Based on the possibilism of the Sprouts, among others, the work of such geographers has been most clearly found in the journal *Political Geography*.

During the same time period, scholars have advanced demands for more and better data needed to address the rich tapestry of international studies. Economic, demographic, and social data of all kinds have been acquired from governments and especially international organizations.[2] Under the aegis of the Data Development for International Research (DDIR) a variety of international conflict datasets have been updated or completed (see Merritt and Zinnes, 1994). The DDIR has also been instrumental in reinvigorating and furthering the collection of event-datasets, including support for new data collection and handling technologies (see Merritt, et al, 1993; Duffy, 1994).

The purpose of this article is both to link and broaden these two trends, by providing a brief introduction to another technology of data acqusition and analysis-- geographic information systems (GIS). GIS is a tool of potentially great relevance (as yet untapped) to international studies scholars, including researchers who do not currently think of themselves as students of "geopolitics." In the next section we will introduce GIS technology in general. This will be followed by an introduction to one specific GIS system-ARC/INFO. The last section will demonstrate how the ARC/INFO GIS is being applied to a research project concerned with a reconceptualization of the idea of "borders," and how the ARC/INFO data could be used in the study of international interactions.

GEOGRAPHIC INFORMATION SYSTEMS

Geographic information systems, developed through the early to mid-1960s, are now the focus of a large literature produced by geographers and regional scientists.[3] As could be expected, there are many approaches and perspectives on GIS. However, some simple definitions can be provided:

• A GIS is designed for the collection, storage and analysis of objects and phenomena where geographic location is an important characteristic or critical to the analysis (Aronoff, 1989: 1).

• A GIS is an organized collection of computer hardware, software, and geographic data designed to efficiently capture, store, update, manipulate, analyze, and display all forms of geographically referenced information (Dangermond, 1992: 11-12).

It is important to understand that a GIS is a *tool*, founded on a variety of computer technologies, that permits the handling of data concerned with the location-- or, more broadly, the *spatiality*-- of physical phenomena and human artifacts. A GIS permits the integration of data about the spatiality of phenomena along with data about other characteristics of those phenomena. More technically (Dangermond, 1992: 12):

GISs can store geographically referenced (cartographic or spatial) data in a raster (grid or cellular-based) data structure or in an *x,y* coordinate reference-based (vector) data structure as points (nodes), lines (arcs), and polygons (bounded by arcs, inclosing an area)... GISs make use of a variety of coordinate referencing systems to locate features on the earth relative to others; these coordinate systems, in turn, make use of a variety of map projections to transform earth references onto a two-dimensional

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surface (the map). Modern GISs also typically store the topology (spatial relationships between connecting or adjacent features) of mapped features in the database. The information pertaining to the various spatial features... is stored typically as attributes (characteristics of a mapped feature) in tabular files linked to the feature often in special database management systems (DBMSs).

In order to perform the functions noted above, and to be considered a true GIS-- having the ability to create new information that goes beyond computer mapping-- a system must include the following four major components (Marble, 1990:10):

1) A data input subsystem which collects and/or processes spatial data derived from existing maps, remote sensors, etc.

2) A data storage and retrieval susbsystem which organizes the spatial data in a form which permits it to be quickly retrieved by the user for subsequent analysis.

3) A data manipulation and analysis subsystem which performs a variety of tasks such as changing the form of the data through user-defined aggregation rules or producing estimates of parameters and constraints for various space-time organization or simulation models.

4) A data reporting subsystem which is capable of displaying all or part of the original database as well as manipulated data and the output from spatial models in tabular or map form.

THE ARC/INFO GEOGRAPHIC INFORMATION SYSTEM[4]

ARC/INFO, developed and supplied by Environmental Systems Research Institute, Inc. (ESRI), is one of the most widespread commercial GISs in use globally. Its strengths, in part, reside in its ability to integrate many kinds of data, as well as "an open architecture which allows it to be linked to a number of relational database management systems" (Peuquet and Marble, 1990b:91). ARC/INFO employs a "georelational" approach, which abstracts "geographic information into a series of independently defined layers or coverages, each representing a selected set of closely associated geographic features (e.g., roads, streams, and forest stands)" (ESRI, 1992:14). Another advantage of ARC/INFO is the flexibility it provides, allowing users to employ any combination of features across any combination of coverages to capture the complexity required by the research in question.

The research project discussed below is based on the ARC/INFO GIS housed in the Humanities and Social Sciences Computing Lab at the University of South Carolina. Data for this project is from the Digital Chart of the World (DCW), produced by ESRI for the Defense Mapping Agency in 1992. The data contained in the DCW (available on four CD ROM disks) was derived primarily from maps in the Defense Mapping Agency Operational Navigation Chart series that were used to generate a 1:1,000,000-scale vector database covering the entire surface of the earth. Because of the enormous spatial areas and quantities of data associated with the DCW, data is organized and stored in 2,094 five degree (latitude-longitude) square tiles. All data, at the 1:1,000,000 scale, for a given area of the world is stored in its corresponding data tile.

Table 1: List of Data Layers in the ARC/INFO Digital Chart of the World

Political and Oceans	Populated Place
Railroads	Roads
Utilities	Drainage
Hypsography	Hypsography Supplemental
Drainage Supplemental	Ocean Features
Physiography	Aeronautical
Cultural Landmark	Transportation Structure
Vegetation	Land Cover
Data Quality	

The large scale database consists of sixteen layers of data. These layers contain data ranging from physical characteristics such as drainage networks, hypsography (elevation and topographic relief), and land cover, to man-made features such as road networks, railroad networks, and aeronautical data. Within each of the data layers, attributes such as length, area, and perimeter, to name but a few, are assigned to their corresponding feature. A seventeenth layer, the Data Quality layer, provides information on the particular source of data for a given tile and when that source was last updated.[5]

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Layers of data in the DCW are organized into four types of coverages depending on the characteristics of a particular feature: point, line, polygon, and net. Point coverages are used for features such as airport location; line coverages are used for roads; and polygon coverages are used for vegetation coverage. The net coverage can contain polygon, linear, and point features. Features such as Political Units are frequently depicted as both polygons and outlined as a linear feature. Any specific class of features is not limited to one type of coverage organization. For example, cities and roads both have area, and as such can be organized as polygons and as points or lines respectively. However, all features are not necessarily organized by all of their possibilities. In the DCW, large urban areas are stored as polygons and points but the road coverage is stored only as a line coverage.

Without going into detail, it should be noted that there are indeed time and memory considerations in planning the extraction and combination of data. Extracting large quantities of data tiles is best accomplished by identifying the individual coverages for specific data tiles desired by the user and inputting their designators into an Arc Macro Language (AML) file.[6] Some coverages take longer to extract than others. Typically these coverages are the net and polygon coverages which are more complex data structures than line and point coverages; (the Hypsography and Drainage Network coverages are typically the largest). Furthermore, in most cases, a larger number of data tiles requires a longer period of time to extract than a smaller number of tiles.

When dealing with large spatial areas such as regions or continents, the necessary time needed to extract data can become extremely long. For example, seventy-eight data tiles covering a portion of Russia and the PRC which contained most of their contiguous land border, required over six hours for extraction. All seventeen layers, containing twenty-seven coverages were requested and extracted by the AML. In another case, the same layers in a group of fifteen tiles in a region of the Middle East required approximately one hour to extract. There is no precise time required to extract a given data tile because of the heterogeneous nature of the earth's surface.[7]

The above discussion is only an elementary introduction to ARC/INFO. Several of the data types and data analysis tools available in the ARC/INFO GIS will be illustrated below in describing its application to the study of interstate borders.

RE-THINKING BORDERS: THEORY AND MEASUREMENT

The location of states, their proximity to one another, and especially whether or not they share "borders," emerges time and again as a key variable in studies of international conflict phenomena: from major power general war (e.g. see Vasquez, 1993 for a model of interstate war which leans heavily on shared borders), to the diffusion of international conflict (e.g. Most and Starr, 1980; Siverson and Starr, 1991), to the analysis of peace between pairs of democracies (e.g. Bremer, 1992 or Maoz and Russett, 1992).

But how exactly do borders affect international interaction? In an investigation of the nature and impact of borders, Starr and Most (1976) conceptualize borders in terms of both opportunity and willingness. One key aspect of borders is that they affect the interaction opportunities of states, constraining or expanding the *possibilities of interaction* that are available to states. States that share borders will tend to have a greater ease of interaction with one another, and thus have greater number of interactions as well (see Boulding's concept of the loss-of-strength gradient, 1962: chap.4; and the seminal work of Zipf, 1949).

Secondly, borders also have an impact on the willingness of decision makers, in that they act as indicators of areas of great importance or salience. Because other states are close, having greater ease of interaction and the ability to bring military capabilities to bear, they are also key areas of external cues (or diffusion). Accordingly, activities in these areas are particularly worrisome, can create uncertainty, and thus deserve attention; (on this point Starr and Most draw from the work of Midlarsky, 1975).

Starr and Most (1976:10) were particularly concerned with the "roles that different types of borders appear to play" in war involvement. Borders were differentiated in terms of homeland borders and borders generated by colonial territories; by land-based contiguity and across-water proximity. These distinctions implicitly dealt with possible variations in ease of interaction and salience. Equally implicit was the notion (later developed by Goertz and Diehl, 1991 and Holsti, 1991) that it was territory *per se*, that was important, and thus proximity along any dimension would effect interstate interaction. The ARC/INFO GIS

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permits us to operationalize and investigate Starr and Most's two dimensions -- opportunity as ease of interaction, and willingness as salience/importance.

Ease of Interaction

Using data available in the DCW's data layers (see again, Table 1), we have constructed indexes of both ease of interaction and of salience. These indexes aggregate values generated from ARC/INFO. They can be used to characterize any border or *border segment* on the globe. In programming the extraction and combination of data, all space was first divided into hexagons. The use of hexagons in a GIS is not common. Although using a square grid is more customary in GIS modeling, hexagons were used in this project for a number of reasons. After the circle, which is not appropriate in this instance of GIS modeling, the hexagon is the most efficient polygon for representing space. The relational qualities of hexagons lend themselves to efficient and accurate path-finding operations through polygon networks.[8] Furthermore, since the pioneering work of Lewis Richardson (1960), there has been a tradition of using hexagons to represent space in the field of international relations.[9] (See figures 1 and 2, following in Appendix A.)

After reviewing all the variables within all of the layers, three were selected to create an index of "ease of interaction" (opportunity or HEXOPPOR). The first variable looked for the presence, absence and density of roads within each hexagon of the locations being studied (for example, Israel and its environs as shown in Figures 1 and 2). Roads included multi-lane divided roads, as well as primary and secondary roads (Layer 4, Road Layer, RDLINE). The second variable was the presence, absence and density of railroads (Layer 3, Railroad Layer, RRLINE). The third variable added the average slope of an area, which was based on the elevation values of contour lines (in mean feet above sea level; Layer 8, Hypsography Layer, HYNET), and was derived from a digital terrain model by converting the hypsography into a triangulated irregular network.

Each of these values was investigated for a *buffer* area of 10,000 meters on each side of all international borders, (thus, calculating values for all hexagons within 10,000 meters on each side of any border). The completion of the processing of the different coverages for roads, railroads and hypsography produced a HEXOPPOR polygon attribute table.[10] This, in effect, is an ease of interaction index (which runs from 0 to 373) representing how "saturated" a hexagon might be. For example, a value of 0-124 as shown in Figure 1, would represent the least saturated hexagons and thus have the *least* ease of interaction-- no roads or railroads plus difficult terrain; an index of 248-373 would indicate the most saturated hexagons, and thus areas of *greatest* ease of interaction. Thus, the least saturated hexagons are those which are most difficult to move across, indicated in Figure 1 by white hexagons. The most heavily saturated hexagons are the most easily traversed, and are represented by the darkest hexagons. It should also be noted that after the summation of the index values, the new HEXOPPOR coverage (or new index) is ready for cartographic output, such as shown in Figure 1, or as data input which can be used with other variables in statistical analyses.

Looking at Figure 1, note that the ease of interaction can vary along any single border that a state might have with a contiguous neighbor. The HEXOPPOR variable can be used to indicate this variation along any single border (or "arc", for example Israel's border with Lebanon). In Figure 1 any particular portion of a border can be characterized as to its degree of permeability. While not done in Figure 1, HEXOPPOR could also be averaged along an entire arc or border in order to classify that border as one with high, medium, or low ease of interaction; (that is, we could compare the average ease of interaction along Israel's border with Egypt to that of the border with Lebanon).

Salience

HEXOPPOR is an indicator of opportunity for interaction-- how easy it is to move across some area. The salience dimension is concerned with the importance or value of territory along or behind a border. The salience index, HEXSALIENCE, was developed in much the same fashion as HEXOPPOR. After reviewing the various coverages, the salience or importance of a border area was determined by places of population concentration, airfields, and selected cultural features located within a 50,000 meter buffer of the region's borders.[11] The features within the buffer were isolated by performing an *identity* of the feature and buffer coverages; the coverage was then *intersected* with the hexagonal coverage HEX-SALIENCE.[12] This process identified individual

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features, whether they be an airport, power plant, refinery or a military barracks, with a unique hexagon number, and a determination of how many airports, areas of urban concentration, and cultural features occurred in each individual hexagon. Any hexagon that contained a capital city, however, was automatically coded with the highest value found in any hexagon in that area (in the case of Figure 2, eight features).

The notion here is that, again, borders may differ in their importance, in terms of where people live, where the capital city is located, where significant elements of the transportation, military, or economy systems are situated. Portions of borders where more of these items are located, (here within a 50,000 meter buffer near that border), could be seen as more important or salient (in Figure 2, the darker hexagons) than segments without population centers, or economic, military or transportation facilities. And, again, each separate arc (for example, Israel's border with Syria) could be categorized as one with low, medium, or high salience.

"Vital Borders"

The use of a GIS dataset, then, permits a new mechanism for operationalizing a state's borders. We can now go beyond simply noting the existence of a border, or its length, or noting its "type" (eg., contiguous land or across-water). Through the indexes generated, we can attach values (nominal, ordinal or interval) to the ease of interaction a border, or border segment provides, and/or the importance of any particular border or border segment. These two dimensions can be used separately or combined. A border with high values on both could be considered a "vital border." Recall that Most and Starr (1989) argue that opportunity and willingness are *jointly* necessary and sufficient conditions for certain types of behavior, and that they are related to each other in complex ways (see also Cioffi-Revilla and Starr, 1995). Thus, given that each dimension taps separate phenomena, and that each can affect the other in different ways under different conditions, the importance of each dimension (individually or jointly) will vary with the specific research question. For example, using both dimensions as well as buffers of varying distances, it would be useful to see if vital borders correspond with Boulding's (1962:265) idea of a "critical boundary":

> The legal boundary of a nation, however, is not always its most significant boundary. We need to develop a concept of a *critical boundary*, which may be the same as the legal boundary but which may lie either inside it or outside it...The penetration of an alien organization inside this critical boundary will produce grave disorganization... War, therefore is only useful as a defense of the national organism if it is carried on outside the critical boundary (emphasis in original).

While perhaps not an entirely novel interpretation, Figures 1 and 2 clearly highlight how Israel's vital border (critical boundary) was vulnerable until the 1967 war, and the difficulty Israel faced in negotiating the complex tangle of peace and territory. Figure 1 shows that the areas of the greatest ease of interaction are along the coast, and along the basically north-south segment of the West Bank bulge that most closely approached the coast (capturing particularly the road and transportation networks in those areas). Figure 2 also indicates the importance of the area between this border segment and the coast. The combination of dimensions (using both quantitative and visual measures) approximates a vital border; and until 1967 constituted part of Israel's border with Jordan.

Conversely, Figure 1 shows that the border along the Jordan river valley, created after the 1967 war, is an area with the greatest difficulty for interaction (as is the border on the Golan Heights), and one with few population areas or important facilities (shown in Figure 2). The figures demonstrate a case where the legal boundary and critical boundary did not appear to coincide. Much of Israeli strategic thinking since 1967 was based on fighting a war at or outside the Jordan river border, and *not* along the vital border along the western bulge of the West Bank area.

In one of the first applications of a GIS to international relations research we have attempted here to indicate the possible utility of GIS-generated data and analysis to international relations scholars. The ARC/INFO GIS, in an uncommon use of a GIS, has been used to operationalize two dimensions of borders. Even with simple cartographic representations we are able to look at important questions of international theory and practice. As part of a broader data set, the GIS-generated data could be used to look at such questions as which types of borders are most or least related to spatial diffusion, and whether or not it is the *nature* of the border rather than numbers of borders that affect conflict behavior. What sorts of borders can

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be found between states in enduring rivalries? What is the nature of the territory over which conflicts arise? Which types of territory or borders are related to crises or militarized interstate disputes? We hope we have begun to demonstrate that questions such as these can be addressed in new ways by using the data and analytic tools provided by geographic information systems.

Acknowledgements

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Endnotes

[1]For works representing a geographical/ geopolitical approach see especially WARD (1992), STARR and SIVERSON (1990). For applications of diffusion models see SIVERSON and STARR (1991); MOST, STARR and SIVERSON (1989). For the role of territory in the development of international conflict proceses, see GOERTZ and DIEHL (1991) and K.J. HOLSTI (1991). With the development of its extensive dataset containing all states and other entities in the international system since 1816, and all of the borders that each of those entities had for each year, the Correlates of War project has helped to encourage various kinds of geopolitical analyses (e.g., see GOCHMAN, 1992).

[2]Examples of the variety and richness of such data can be found in the *Human Development Report 1994* (New York: Oxford University Press, 1994) published by the United Nations Development Programme (UNDP); *World Development Report 1993* (New York: Oxford University Press, 1993) published by the World Bank; or *The World Factbook, 1994-95* (Washington: Brassey's, 1994) published by the CIA.

[3]For just a sample of GIS overviews, see the edited volumes of MAGUIRE, et. al. (1991), or PEUQUET and MARBLE (1990a). See also widely used textbooks such as ARONOFF (1989). In addition to regularly published symposia, the *International Journal of Geographical Information Systems* began publication in Britain in 1987.

[4]This section is based on material provided by ESRI (1992), *ARC/INFO: GIS Today and Tomorrow*. For a briefer introduction to ARC/INFO, see also PEUQUET and MARBLE (1990b).

[5]In addition to the large scale database, the DCW contains a utility directory, referencing such material as small scale reference maps, data quality information, and DCW technical information. The various utilities are useful in providing base maps for cartographic output and verifying data extraction from the CD's.

[6]For this project, appending the data tiles together was also performed at the same time as extraction. By incorporating the ARC/INFO APPEND command into the AML, the specified data from individual tiles was extracted and joined together in one process. Note also that the analyses reported here were conducted on a UNIX workstation, not as a PC application.

[7]The same factors that affect extraction time influence the hardware required to store data once it is extracted. The Hypsography layer for forty tiles covering Pakistan, and large portions of India and the PRC consumed over twenty megabytes of storage space. Similarly, the Drainage Network layer consumed over fifteen megabytes of disk space. These examples represent the largest of coverages.

[8]Although path-finding operations were not performed in this part of the study, the hexogonal model possesses those advantageous qualities should path-finding operations be performed in the future.

[9]See, for example, RICHARDSON (1960: chap.8) on the effects of language on war between groups of humans.

[10]Maps (in color) presenting each of these variables, as well as all of their various combinations, were generated. Figure 1 presents only one possible presentation of the final **HEXOPPOR** index for the polygons along Israel's borders and surrounding regions. All of the color maps also indicate buffer areas; however, buffers are not shown on the black and

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white maps here to increase clarity of presentation. We should also stress that Figures 1 and 2 are simply screen captures of maps generated by ARC/INFO, and not special cartographic documents.

[11]Areas of urban concentration including urbanized areas and capital cities were extracted from the Populated Place Layer, Layer 2 (PPPOLY and PPPOINT). From Layer 13, the Aeronautical Layer, active civil and military airports were identified (AEPOINT). The Cultural Landmark Layer (Layer 14) provides a catalogue of items that would indicate the importance of an area, including: military camps, forts, oil wells and refineries, power plants, water tanks, etc.

[12]In the ARC/INFO software the *identity* operation overlays two coverages (A and B) so that all of the features in coverage A and coverage B are combined to form a new coverage C. The *intersect* operation also overlays two coverages; however, when coverage A is overlayed with coverage B, only those features (airports, cities, etc.) in A that fall within the designated polygon boundaries of B (hexagons) are retained to form a new coverage C.

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APPENDIX A:

Figure 1: Measuring Opportunity for Interaction (HEXOPPOR)

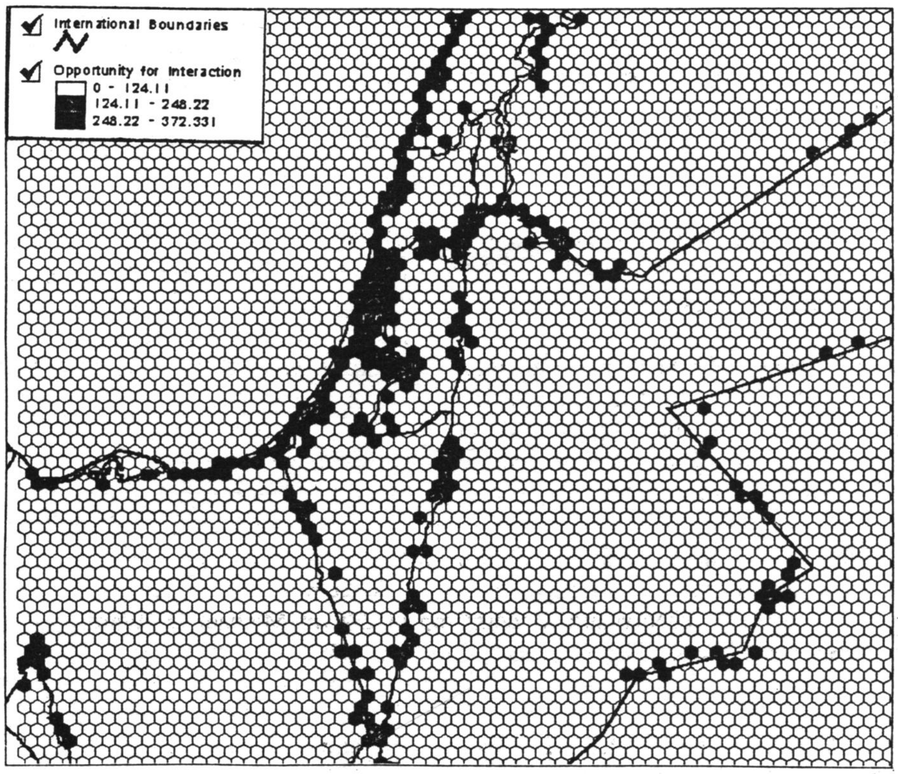
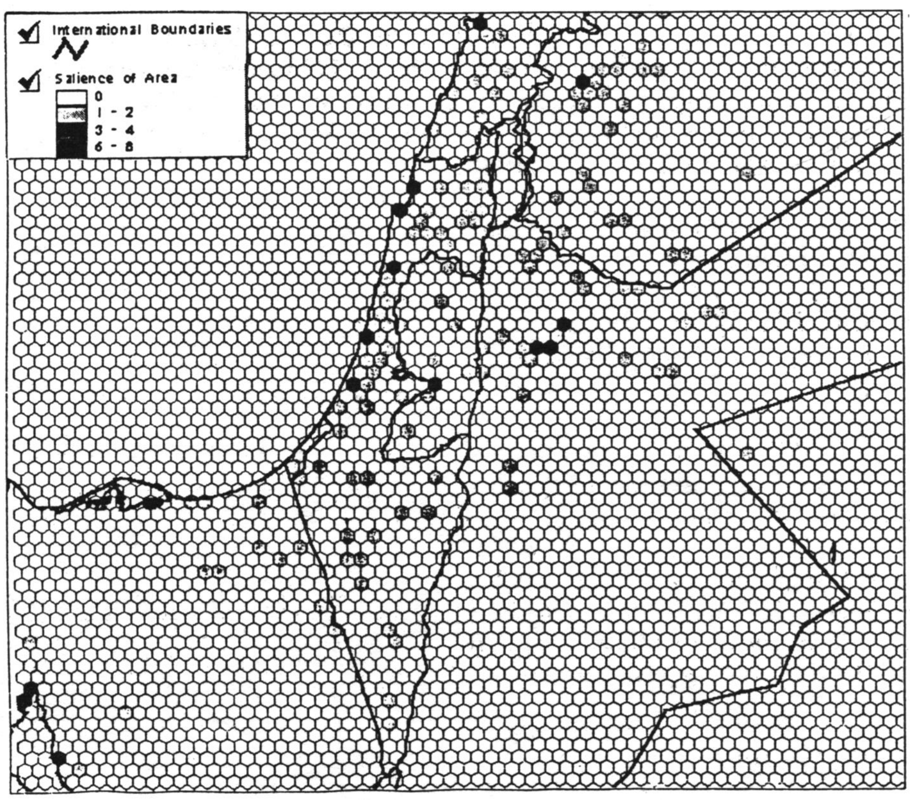


Figure 2: Measuring the Salience of Areas (HEXASALIENCE)



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