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COMPUTER-AIDED QUALITATIVE GIS: A SOFTWARE-LEVEL INTEGRATION OF QUALITATIVE RESEARCH AND GIS

Jin-Kyu Jung

ABSTRACT

A growing number of geographers are conducting mixed methods research involving the integration of quantitative and qualitative data in GIS. Contributing to these efforts, this chapter describes software-level modifications that adapt GIS to enable inclusion of qualitative data as well as interpretive codes associated with these data. These innovations enable GIS to serve as a platform for dynamically integrating quantitative and qualitative data throughout the analysis process. Further, this chapter shows how GIS may be meshed with computer-aided qualitative analysis software (CAQDAS) to support inductive interpretive analysis. The value of GIS is in its ability to represent both qualitative and quantitative data along with their spatial information, and the value of CAQDAS lies in its ability to provide better means of storing, managing, and analyzing qualitative data. The system described here enables researchers to take advantage of all of these capabilities as they are working with multiple forms of data. Further, the linkage between GIS and CAQDAS that I have developed enables researchers to carry out many different forms of analysis, such as exploratory data visualization, conventional forms of spatial analysis, grounded theory, and other approaches.

INTRODUCTION

GIS is commonly used to display and analyze urban demographic information such as population, racial distributions, and median income, and such GIS-based data are widely used by policy makers for making plans and decisions that affect urban neighborhoods. But none of these data enable us to explore local people's individual lived experiences, or their attachments and social ties to their neighborhoods. Such neighborhood-level local knowledge can offer researchers and policy makers alike 'well-grounded, rich descriptions, and explanations of processes in identifiable local contexts' (Miles and

Huberman, 1994: 1). Researchers in public participation GIS (PPGIS) have developed ways of incorporating local knowledge into GIS-based maps and facilitating its inclusion in planning processes that use GIS (Aitken and Michel, 1995; Al-Kodmany, 2002; Barndt, 1998; Corbett and Keller, 2005; Elwood, 2006; Elwood and Leitner, 1998; Ghose, 2001; Ghose and Huxhold, 2001; Harris and Weiner, 1998; Weiner and Harris, 2003). But these researchers and others illustrate the challenge of including local knowledge in GIS-based data structures and GIS-based analysis, because it is often represented in forms such as texts, image, audio, and video, rather than numbers or maps. The project described in this chapter addresses this challenge, developing ways of incorporating well-grounded contextualized qualitative data, which reflect the everyday lives of people and society, directly into geographic information systems. More broadly, this project contributes to qualitative GIS methodologies by developing ways to both include qualitative forms of data and carry out qualitative analysis techniques. These kinds of qualitative GIS practices produce new ways of using GIS in research, leading us to a form of mixed methods practice that weaves together GIS and qualitative research.

A growing number of geographers are using GIS as part of mixed methods research that incorporates both quantitative and qualitative forms of data and analysis (Gilbert and Masucci, 2005; 2006; Kwan and Knigge, 2006; McLafferty, 2005a; 2005b; Schuurman and Pratt, 2002; Sheppard, 2001). Building on these approaches, I have developed a new approach that integrates GIS with qualitative data and computer-aided qualitative analysis, a technique I refer to as computer-aided qualitative GIS (CAQ-GIS). This chapter presents the key concepts and specific software innovations through which I implement this new approach for blending qualitative research with GIS. In the second section, I conceptualize the 'qualitative' in 'qualitative data', drawing on existing literature on critical visual and qualitative methodologies, and review existing approaches for handling qualitative data in GIS. I argue that there are two components to a robust qualitative GIS which existing approaches have not yet fully integrated: incorporating qualitative data into GIS data structures, and supporting qualitative analysis techniques that can be brought to bear upon these data. In the third and fourth sections, I present the software innovations I have developed to achieve these goals. The system I have developed, CAQ-GIS, enables storage of qualitative data such as images directly into GIS data structures, and facilitates inductive interpretive analysis of these data using GIS software and a computer-aided qualitative data analysis software (CAQDAS). I demonstrate the capabilities of this integrated system using examples drawn from an ethnographic research project on children's urban geographies carried out in Buffalo, New York.

The value of GIS is in its ability to represent both qualitative and quantitative data along with their spatial information, and the value of CAQDAS lies in its ability to provide a means of storing, managing, and analyzing qualitative data. With the techniques I have developed, GIS and CAQDAS are integrated with each other, enabling the researcher to take advantage of all of these capabilities in a systematic and coordinated way. The system I have developed is intended to support innovative mixed methods research, developing software-level structures that will support researchers' efforts to integrate spatial analysis, qualitative visualization, and other qualitative analysis techniques.

EXISTING CONCEPTUALIZATIONS AND STRATEGIES FOR SUPPORTING QUALITATIVE VISUALIZATION IN GIS

An important first step toward developing qualitative approaches to GIS is conceptualizing precisely what is meant by 'qualitative' and how and where this 'qualitative-ness' is present: in spatial data, in visual representations of these data, in data analysis techniques, or in other components and processes of GIS. In this project, I focus upon incorporating qualitative data in GIS and facilitating qualitative analysis with GIS software. In doing so, I conceive of qualitative data as those forms of information that provide well-grounded, richly contextual descriptions of everyday spaces and activities, collected through research methods such as interviews, oral histories, sketch mapping, photography, or drawing. That is, I understand qualitative data to be more than simply those data that are non-numerical. Rather, qualitative data are representations of the experiential knowledge of individuals or groups, and the interpretations and meanings they ascribe to these representations.

Researchers in critical cartography and critical geography more broadly have shown how visual representations such as maps are socially embedded and constructed, laden with interpretive contextual meanings (Crampton and Krygier, 2006; Dorling, 1998; Fiedler et al., 2006; Harris and Harrower, 2006; Harris and Hazen, 2006; Johnson et al., 2006; Kanarinka, 2006; Krygier, 2006; Wood, 2006). Writing on critical visual methodologies, Rose (2001) notes that images are made and used in all sorts of ways by different people for different reasons. Or, as Krygier notes, 'Visualization is not arbitrary but more concrete because we have a point to make, a story to tell, and knowledge to communicate' (1999: 48). Following from these perspectives, *any* image may be qualitative, if it encodes and visualizes qualitative information. Further, a GIS-based map can be seen as an image that produces and represents qualitative information. This perspective opens the door to considering many ways that qualitative information may be included in a GIS by including images.

But it is critical to note that not all images function as qualitative data. A satellite image or air photo, for example, is often considered a reflection or exact mirror of the 'real world', perhaps detailing the physical structure of a neighborhood. In an urban GIS application, such an image might be used to show the presence or location of streets, buildings, or parks, or to measure and check the accuracy of other spatial data files. These types of images, which I refer to here as 'outlook images', do not function as qualitative data, because they do not allow us to discern anything about social relations, different experiences of places, or meanings and identities that different actors may attach to these places.

In contrast, 'qualitative images' are those that convey multiple meanings of a place, such as neighborhood or community.[1] Qualitative images may be maps, photographs, sketches, or other visual forms of information that carry the interpretations, meanings, and experiential knowledge of the individuals or groups who created them. For example, Figure 7.2 includes some photographs of the West Side neighborhood of Buffalo, New York. I created these images when I visited this area as a researcher. The photographs are not simply randomly selected snapshots. Rather, each is an image I recorded as an exemplar of key aspects of the neighborhood environment. So the photograph is already a representation that tells a story. Different stories and meaning might be conveyed if different researchers or local residents took photographs for inclusion in the GIS. To differentiate this type of image from 'outlook images', I refer to them as 'neighborhood images'.

As scholars writing on critical visual methods have shown, interpreting the meanings associated with such qualitative images is challenging, particularly in efforts to interpret meanings signified in an image created by another person (Kwan, 2002a; Rose, 2001). Using images in a GIS as a means of incorporating qualitative information will of course carry these same difficulties. But more immediately, there is the practical challenge of how to incorporate such qualitative knowledge in digital form in a GIS. Several approaches have been developed by other researchers. Some focus upon including local knowledge, such as unique locally specific place names, into a thematic layer in the GIS (Flavelle, 1995). Others rely on a multiple methods research design, using GIS-based analysis and representation in combination with other forms of data analysis and representation, instead of making qualitative data and analysis part of the GIS itself (Dennis, 2006; McLafferty, 2002; Pavlovskaya, 2002; 2006).

Still other scholars use the visualization capabilities of GIS to integrate or link multiple forms of evidence with GIS maps and the objects shown in them. Pavlovskaya (2002), for example, in a study of urban economies in post-Soviet Moscow, used information such as census data to characterize the formal monetary economy, and information household interviews to identify key sites and characteristics of the informal non-monetary economy. Both kinds of evidence were represented in GIS-based maps. But the information drawn from the household interviews was not incorporated directly. Rather, this narrative information was used to identify key sites and their characteristics, which were then encoded in the GIS database and represented on the map. This approach involves a transformation of primary data, a sort of 'quantification' of qualitative information so that it might be visualized in tandem with other forms of evidence such as the census data.

Pavlovskaya (2002) shows how incorporating multiple forms of evidence greatly strengthens the explanatory power of her GIS-based analysis. However, the process of quantifying qualitative information has limitations. Specifically, in transformation of original data, much of the rich contextual interpretive knowledge communicated in the interview narratives is surely lost. Quantifying qualitative data for visualization is only a partial solution, because only a portion of the 'qualitative-ness' of the knowledge gathered from households is included.

One way of avoiding the problems posed by such transformations is to include the original data directly, and connect it to the GIS. The most common approach for doing so is using hyperlinks or hypermedia tools to link multimedia data such as text, images, audio, and video to spatial objects represented in a GIS. For example, Al-Kodmany (2000) uses multimedia approaches to include panoramic photographs and video clips of a neighborhood in a GIS as part of participatory environmental design projects. Hyperlinking techniques are an effective way to incorporate multiple forms of knowledge and have been successfully used in many participatory GIS applications to represent diverse experiences, individuals, and social groups (Al-Kodmany, 1999a; Cieri, 2003; Krygier, 1999; 2002; Talen, 1999; 2000; Weiner and Harris, 2003). By including such qualitative data directly, we might be able to preserve the contextual interpretive meanings they contain. But an important limitation of hyperlinking strategies is that the qualitative data are stored outside the GIS database. The hyperlinks simply associate these multimedia data with particular geographic entities that are represented in the GIS (such as a river, a house, or a forest). In this approach, the qualitative data are not georeferenced: they do not contain any explicitly spatial information such as latitude/longitude coordinates. Thus, the qualitative data can be used for GIS-based visualization, but it is difficult to incorporate these data in any other analysis within the GIS, or even to query and retrieve them based upon their location, because these data are not part of the GIS itself.

In sum, these existing strategies have provided important tools for linking qualitative data with GIS. They primarily incorporate qualitative data by visually representing them on the map or alongside the map. But maps are only one component of a GIS. Much of the analytical power of GIS is vested in query, selection, reclassification, and other operations performed upon the data stored in these data structures of the GIS itself. If qualitative data are to be the target of GIS-based analytical operations, they must be encoded directly into the database. In hyperlinking and other visualization-based efforts to include qualitative data in GIS, the data remain external to the GIS. But if qualitative data can be stored directly in GIS data structures, we can carry out analysis of these data without relying on such practices as quantifying qualitative data. Encoding qualitative data in GIS data structures also opens the door to using GIS in concert with qualitative analysis techniques, rather than using GIS only for visualization of multiple forms of data at the final representational stage of research. In the following section, I describe the software-level innovations I have developed to support the inclusion of qualitative data directly into GIS data structures.

ADAPTING GIS DATA STRUCTURES TO STORE QUALITATIVE DATA: THE IMAGINED GRID AND THE HYBRID RELATIONAL DATABASE

My approach for incorporating qualitative data, such as the 'neighborhood images' described in the previous section, into a GIS builds upon the existing data models of a GIS. There is untapped potential in these models for incorporating qualitative data directly into GIS data structures. As Schuurman (2000; 2004) explains, GIS represents geographic objects and their characteristics through an object-based ontology or a field-based ontology. These ontologies are implemented in GIS software through either a vector model or a raster model. In a vector model, geographic objects (such as roads, cities, or conservations areas) are represented using three geometric primitives: points, lines, and polygons. Then, attribute data describing the characteristics of these objects (road type, city population, species present in the conservation area) are associated with the object. Typically, this association is made through a relational database in which some tables define the geographic objects (their locations, shape, size, and so on), and others store the attribute data. The tables are related through some unique identifiers assigned to each entity. A raster data model defines an area through a series of grid cells, and then defines geographic objects within this area by assigning values to each cell. Thus, a geographic object such as a forest is represented by encoding multiple adjacent cells with some value that is assigned to represent 'forest'.

As Schuurman (2000; 2004), Chrisman (1997), and others have illustrated, both raster and vector models establish systematic approaches to representing geographic objects and their characteristics in a digital environment, and facilitate analysis techniques based upon Boolean logic and map algebra. The limits of relying solely upon these approaches have been well explained by Sheppard (1995; 2005). But I find that strategies used in implementing vector and raster models can be adapted to support the storage and analysis of qualitative data. Specifically, I rely upon the raster model's grid structure and the vector model's relational tables to develop two new innovations, which I term the 'imagined grid' and the 'hybrid relational database'. Below I describe these structures and how they might be used in qualitative GIS approaches.

To incorporate qualitative data directly into GIS data structures, my strategy is to create a special layer for storing qualitative data, using techniques from existing data models in GIS. Creating a special layer for qualitative data solves several of the limitations posed by hyperlinking approaches, such as external storage and the absence of spatial identifiers for the qualitative data. I use strategies from the raster model to create this special layer for storing qualitative data. As shown in Figure 7.1, this layer, called the 'imagined grid', comprises regular grid cells overlaying the other data layers in use in the GIS.

Once the imagined grid is defined, qualitative data such as neighborhood images can be stored in its grid cells. However, before the data can be inserted in the imagined grid, they must be georeferenced. I accomplish this by giving each neighborhood image the coordinates from the grid cell to which it is assigned. In the imagined grid, as in any raster, the vertices of each grid cell have coordinates that define their geographic location. These same coordinates may be assigned to the four corners of the neighborhood image that will go into that grid cell.[2] Once each neighborhood image is georeferenced and rectified through this process, location information is associated with it, allowing it to be incorporated directly into the imagined grid. Figures 7.2 and 7.3 illustrate what this approach looks like, when images stored in the imagined grid are represented on the map, together with other data layers. These figures show neighborhood images that were stored in the Imagined Grid, displaying them together with other forms of data: a layer showing streets; a satellite image of the area in Figure 7.2; and in Figure 7.3 a thematic map created with demographic data from the US Census. These data are from the case study I conducted in the West Side neighborhood of Buffalo, New York.

Figures 7.2 and 7.3 begin to illustrate some of the advantages of using the imagined grid to store qualitative data. Because qualitative data are stored in the GIS attribute table, they can be more easily retrieved and used at any stage of the research, especially in analysis. With this approach, qualitative images of neighborhood can be incorporated with other data, both quantitative and qualitative, such as census demographic data, seasonal images, and multi-scale visual data in GIS (Figure 7.1C). Using the imagined grid to include qualitative data, a user could simultaneously visualize multiple forms of evidence, exploring relationships and patterns within and across different data. Such an approach might be particularly useful for a researcher carrying

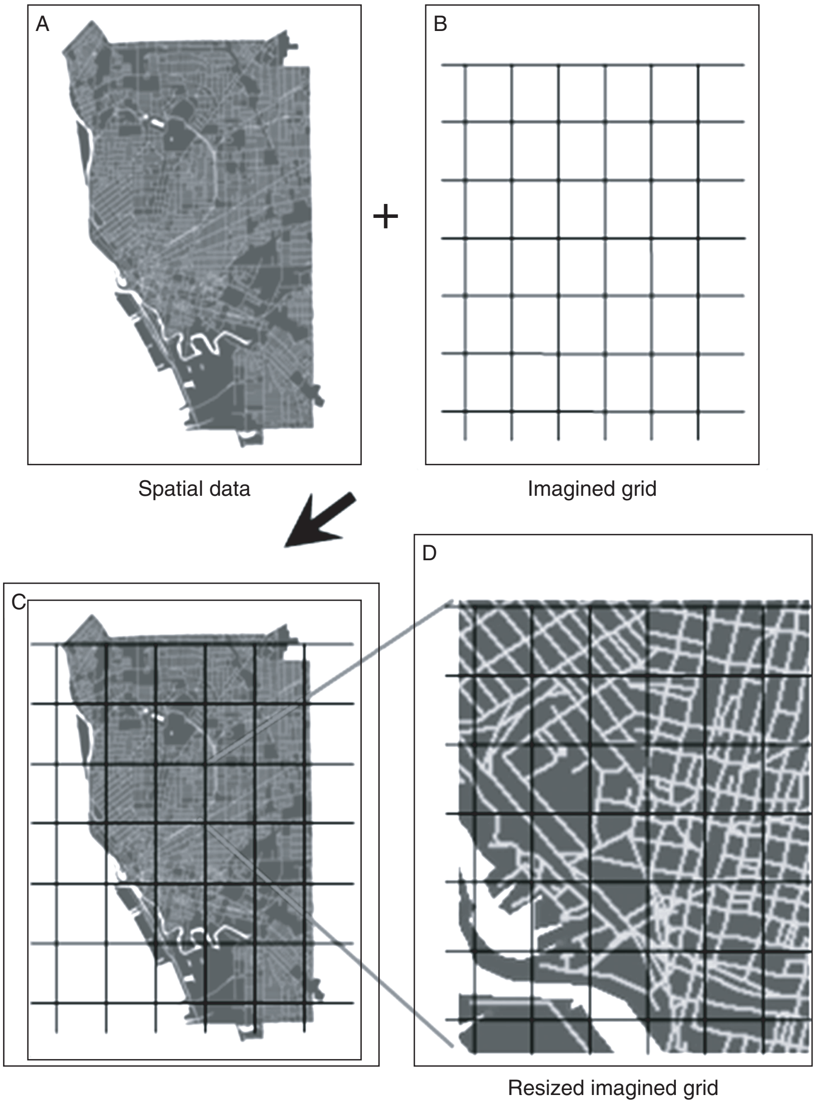


Figure 7.1 The imagined grid

out Knigge and Cope's (2006) grounded visualization technique, an iterative inductive analysis of multiple forms of evidence in a GIS. Another advantage of the grid, practically and technically, is its scalability. As shown in the 'resized imagined grid' in Figure 7.1D, if we change the scale of the map, the neighborhood images are automatically adjusted like other geographical spatial data in the GIS.

Using concepts from the raster model, but adapting them to store qualitative data, the imagined grid is an improved way to collect, store, manage, and visualize qualitative data in GIS. But the imagined grid is still not sufficient alone. It enables

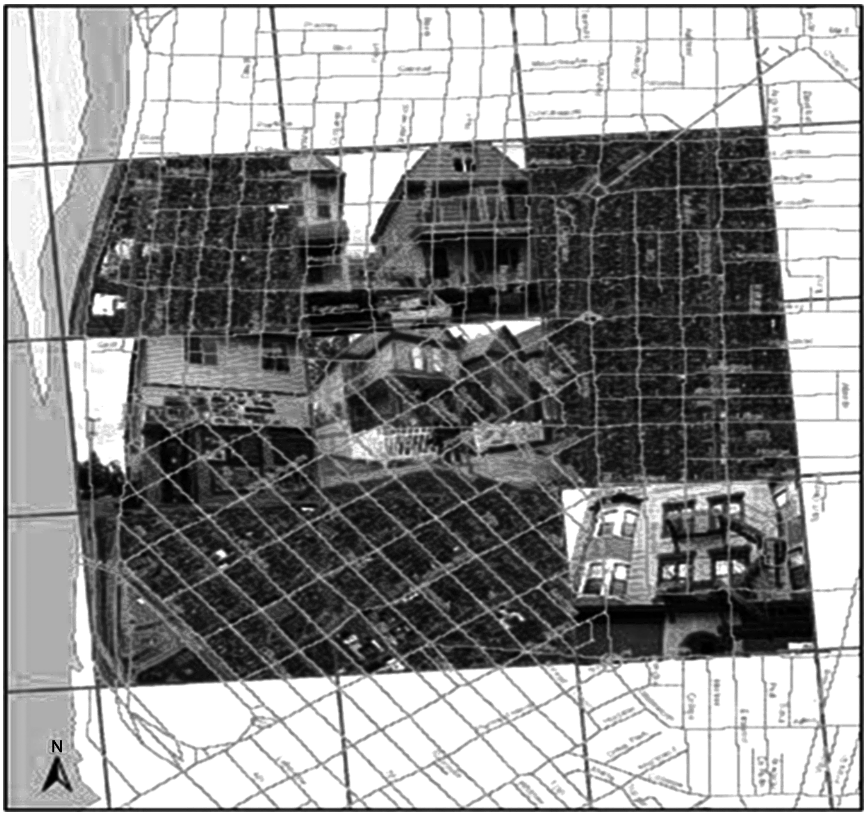


Figure 7.2 Using the imagined grid to visualize qualitative images: neighborhood images displayed with satellite imagery

inclusion of qualitative data into a GIS database, but it can save only one qualitative artifact – a code, an image, a narrative – per grid cell (Figure 7.4A). It would not be possible, for example, to store both a qualitative image and an interpretive code assigned to that image by a researcher in the process of analysis, because there is no way to save more than one piece of information in each cell. This limitation is inherent in raster models. We could create multiple imagined grids to solve this problem, but this is a very inefficient solution in terms of data storage and computation.

I solve this problem with the relational database structure that is commonly used in a GIS to link tables storing attribute data to tables that define the geographic objects in a vector model. The relational database structure enables us to build one-to-many relationships, so that a single record (row) in one table might be associated with multiple records (rows) in another table, as shown in Figure 7.4.

Through relational database structures, we can associate more than one qualitative data attribute with a single grid cell in the imagined grid. First one creates multiple records in the attribute table (called the 'qualitative data table' in Figure 7.4B). Then these records can be used to contain multimedia qualitative data such as images, text,

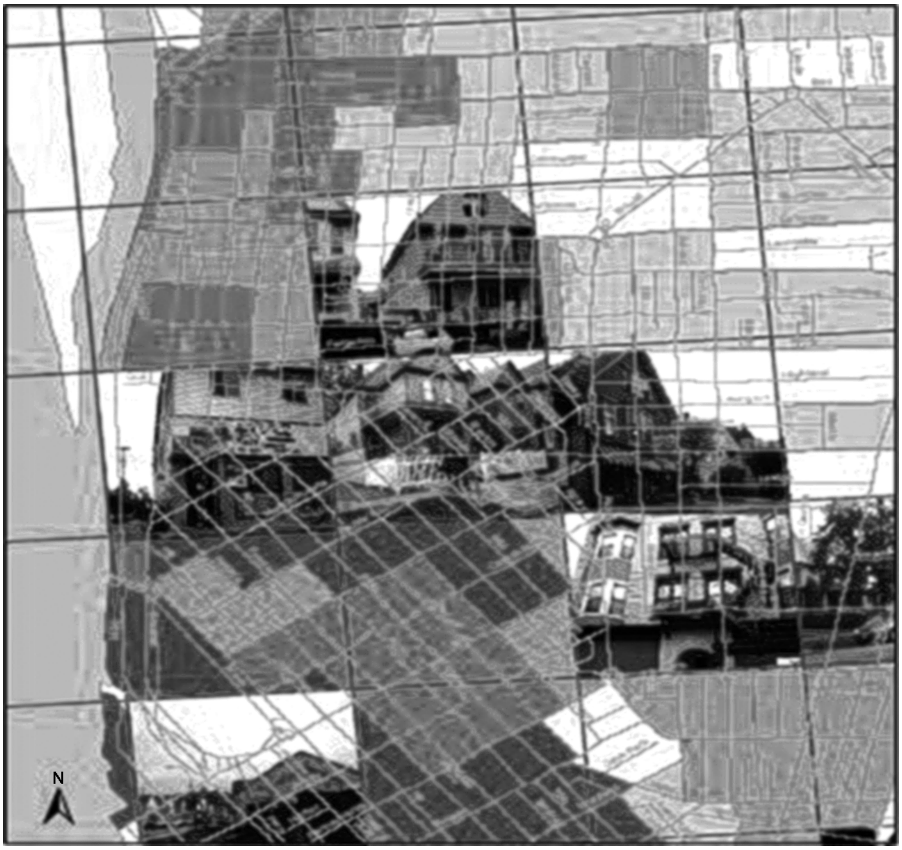


Figure 7.3 Using the imagined grid to visualize qualitative images: neighborhood images with thematic map of demographic data

audio, or video. Additional fields (columns) in this table could be populated with interpretive codes created by the researcher in the process of analysis, as shown in the columns labeled 'Code1' and 'Code2' in Figure 7.4B.

I call this design a 'hybrid relational database'. A hybrid relational database consists of an imagined grid (identified as the 'spatial data table' in Figure 7.4A), plus the relational table that contains original/raw qualitative data or interpretive codes (identified as the 'qualitative data table' in Figure 7.4B). The qualitative data table is relationally joined to the spatial data table using a unique identifier. As shown in Figure 7.4, the qualitative data table can associate multiple records (rows) with a single record/object in the spatial data table. This design is 'hybrid' in several ways: it can incorporate qualitative data and quantitative data, it can contain multiple media, and it can contain 'raw' data and interpretive analytical information from the researcher.

Together, the imagined grid and the hybrid relational database can support visualization and inductive analysis of multiple forms of data. To demonstrate this capability, I created these structures in ESRI's ArcGIS 9.2 while participating in a research project

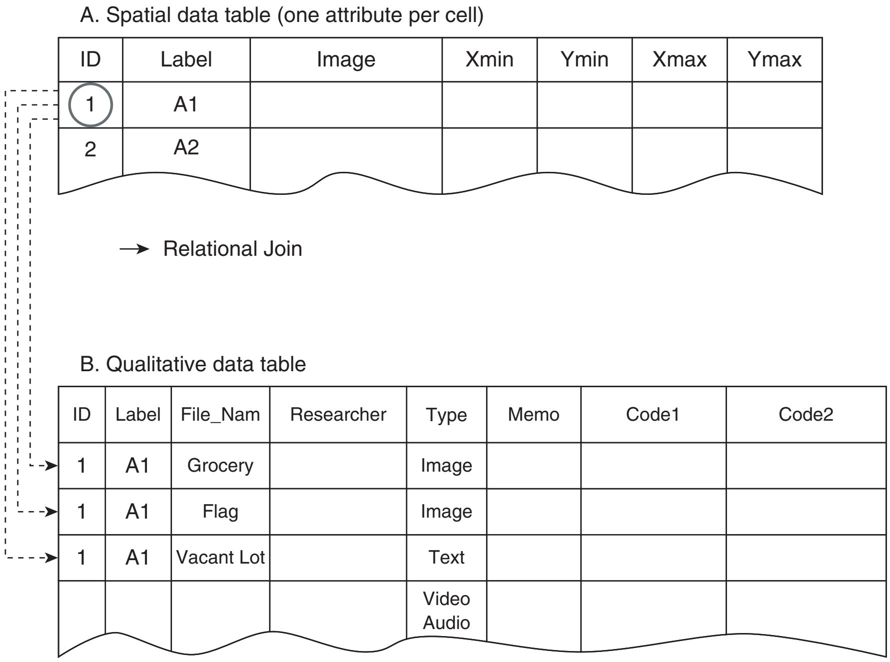


Figure 7.4 Hybrid relational database

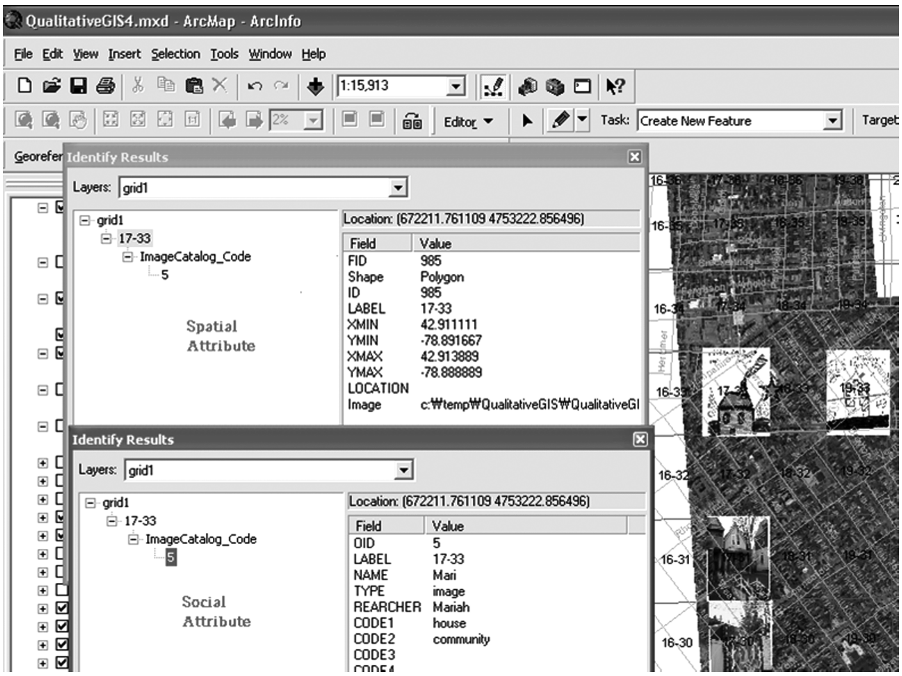


Figure 7.5 Information search result in CAQ-GIS

on children's urban geographies. I had gathered multiple forms of data, including conventional forms of GIS-based data (such as census data or satellite images) as well as qualitative images, such as the neighborhood images shown in Figures 7.2 and 7.3. Other qualitative images included paintings created by participating children when I asked them to express their thoughts about the meanings of community in any medium. Figure 7.5 is a screenshot that shows some of the visual displays and tables that resulted when I stored all of these data in a GIS using an imagined grid and a hybrid relational database.

Using these structures, the data may be explored in many ways. If we want to know more about the sketch shown next to the star symbol on the right of Figure 7.5, we can use ArcGIS tools to click the image and access related information. The two 'Identify Results' windows in Figure 7.5 show the results of such an action: retrieval of the tabular information contained in the spatial and qualitative data tables of the hybrid relational database. The spatial data table, which is the upper 'Identify Results' window, shows the georeferenced information that defines the location of the qualitative image (the sketch) stored in this cell of the imagined grid. The fields XMIN, YMIN, XMAX, and YMAX contain the latitude and longitude information of that grid cell. The qualitative data table, shown in the lower 'Identify Results' window, stores multiple types of qualitative data, as well as information such as type of data, researcher's name, label, and description of data. The association of multiple artifacts or attributes in the qualitative data table with each record in the spatial data table is made possible through the relational join function in ArcGIS.

Together, the imagined grid and the hybrid relational database enable multiple forms of qualitative data to be included, enabling a user to explore and visualize these data in a GIS. By including the original qualitative data directly, rather than transforming it into quantitative forms, the full contextual richness of these data is preserved. Georeferencing and storage of qualitative data in GIS data structures addresses many of the limits of hyperlinking strategies. Further, the possibility of storing interpretive codes in the hybrid relational database lays the foundation for using qualitative techniques to analyze these data. But simply storing data and codes in a GIS is somewhat limited in terms of the qualitative analytical operations that might be performed in the GIS itself. In the following section, I show a way of linking my GIS structures with computer-aided qualitative analysis software, so that the many analytical functions of such software might be brought to bear upon the data stored in the imagined grid and the hybrid relational database.

LINKING GIS AND COMPUTER-AIDED QUALITATIVE ANALYSIS SOFTWARE: CAQ-GIS

My efforts to support qualitative data analysis techniques in a GIS environment focus specifically on inductive techniques such as grounded theory. Grounded theory is an inductive analysis technique that enables the generation of theoretical propositions from qualitative data. In grounded theory, researchers are not testing preconceived theoretical propositions but rather are performing iterative inductive analysis that will allow the theory to *emerge* from the data (Strauss and Corbin, 1998: 12–14). Grounded theory is especially useful in dealing with the complexity and nuance of qualitative data because it emphasizes exploring multiple possibilities or interpretations; using multiple media to represent and explore data, including visual aids such as diagrams, memos, and conceptual 'networks'; and using non-linear forms of thinking such as iterative analysis. Overall, grounded theory is a technique that conceives of analysis as a dynamic interplay between researchers and their data (Charmaz, 2000; Chiovitti and Piran, 2003; Strauss and Corbin, 1997; 1998).

The heart of grounded theory is the process of coding (Lonkila, 1995). Coding is a way of evaluating and organizing data to understand meanings in the text in a systematic way (Cope, 2003; 2005; Miles and Huberman, 1994). Codes are labels for assigning units of meaning to the particular qualitative data artifacts, such as a qualitative image or a textual narrative. Codes may come from the researcher's conceptual framework, or from words and themes contained in the data themselves. The process of creating and assigning codes is a kind of analysis, directed at finding meanings and relationship within the data by differentiating or combining data (Miles and Huberman, 1994; Miles and Weitman, 1996). Coding is an important part of analysis because it identifies key ideas and repeated themes. In the process, it is a way of filtering data, creating a manageable dataset, and dealing with a huge amount of information without discarding the detail and importance of the original data (Strauss and Corbin, 1998). Within a grounded theory framework, the process of coding is part of building theory, not testing it, though of course codes and coding processes may be influenced by existing theoretical frameworks (Burawoy, 1991). Researchers have long done grounded theory and coding without using computing technologies, and many still do so. But over the past 20 years, a number of software packages have been developed for helping researchers perform qualitative analysis more efficiently and effectively. CAQDAS packages are designed to assist the researcher in managing the analysis of qualitative data, and help them develop conceptual propositions from their qualitative data.

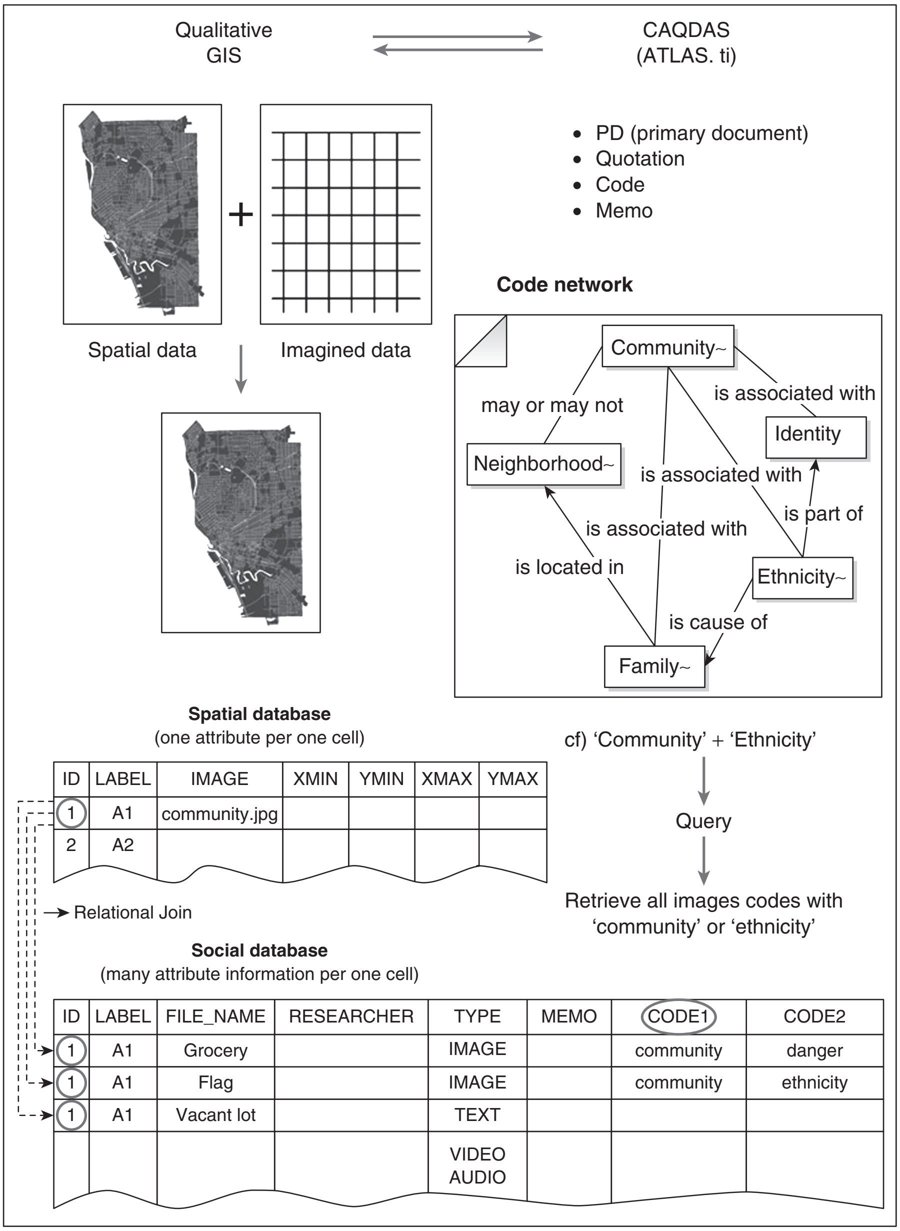
There are many different types of CAQDAS packages in use today, including word processors, text retrievers, text base managers, code-and-retrieve programs, code-based theory builders, and conceptual network builders (Kelle, 1995; Tesch, 1990; Weitzman and Miles, 1995). The search, highlighting, and commenting functions of ordinary word processing programs can be used for coding and grounded theory. Text retrievers do precisely what their name suggests: enable the researcher to search on particular words or phrases, retrieving these instances and often providing a count of their number. Text base managers operate similarly, but have more sophisticated content analysis functionalities for managing large databases (Lewins and Silver, 2006). Code-and-retrieve programs and code-based theory builders incorporate many of these same functions, but also allow researchers to code their data. These types of CAQDAS can also typically include visual forms of data (not only text) and provide visualization tools that researchers can use to create graphic visualizations of connections among themes or codes (Miles and Weitzman, 1996; Weitzman, 2000). The most important point about any of these CAQDAS types is that they do not automate or *do* qualitative analysis. As Weitzman argues, 'Software cannot pull good work out of a poor qualitative researcher, but it can in fact help competent researchers do more consistent and thorough research' (2000: 817). As he suggests, CAQDAS packages provide tools that researchers can use to facilitate their analysis, such as conceptual network tools or the ability to store and retain codes and associations in the data in digital form.

CAQDAS packages have not typically supported spatial data analysis directly, or the inclusion of spatial databases, though geographers and others are calling for such capabilities (Crang et al., 1997; Hoven, 2003). Further, several GIS researchers have proposed taking advantage of these strong data management and analysis functions of CAQDAS to support qualitative analysis in a GIS environment. Kwan (2002b) notes that GIS and CAQDAS both support visualization and query of visual forms of data or evidence, links to qualitative data such as photos and voice clips, and query tools based upon Boolean operations. Thus, she proposes, linking these two softwares could be one strategy for supporting qualitative analysis in a GIS environment. While Kwan (2002b) does not implement this proposition in practice, Matthews et al. (2005) have built an interface that tries to combine GIS and a CAQDAS package to support their 'geoethnography' technique. This use of GIS and CAQDAS together to support a very large collaborative ethnographic project is a tremendously important step forward. But it is limited in some ways because the GIS database and the ethnographic database in CAQDAS are still largely separate. In their system, the GIS is primarily used for visualization, with audio, video, image, and text files associated externally through hyperlinks. The ethnographic data analysis is also carried out separately, using the CAQDAS. My approach builds on these existing approaches to more strongly connect the two software systems for the purposes of analysis.

To use GIS with CAQDAS in an integrative way, in support of recursive iterative analysis of multiple forms of data, we need a way to connect the two systems. I propose using qualitative codes to accomplish this, using the codes as an anchor or bridge between GIS and CAQDAS. I refer to the resulting integrated system as a computer-aided qualitative GIS (CAQ-GIS). I choose to use codes to create this link for pragmatic and analytic reasons. Codes and coding are the essential elements of grounded theory, so we must support them in GIS and in CAQDAS if we are to build a truly integrated system for this sort of qualitative analysis. But at the practical level, codes and coding are already embedded in CAQDAS, and my hybrid relational database structure allows them to be integrated into the GIS database as well. This creates a critical link between CAQDAS and GIS. Thus, the codes created by a researcher as s/he analyzes qualitative data function as a 'bridge' that connects these two types of software.

I implemented this approach using my ArcGIS and a CAQDAS package called ATLAS.ti, an excellent code-based theory builder program. Its qualitative data storage and analysis tools are organized into several modules within the software. In ATLAS.ti, a project or 'hermeneutic unit' may comprise primary documents, smaller quotations, codes, and memos (researchers' notes that can be associated with primary documents, quotes, and so on). ATLAS.ti can help researchers to organize a variety of data types such as text, graphics, audio, and video data files. This capability of handling text-based data as well as non-text-based multimedia data is the essential strength that distinguishes this program from other CAQDAS programs and makes it ideal for my approach.

Figure 7.6 summarizes the system that I developed for linking GIS with CAQDAS. It outlines the structures that comprise CAQ-GIS in its entirety. The qualitative GIS,



ID	LABEL	IMAGE	XMIN	YMIN	XMAX	YMAX
1	A1	community.jpg				
2	A2					

ID	LABEL	FILE_NAME	RESEARCHER	TYPE	MEMO	CODE1	CODE2
1	A1	Grocery		IMAGE		community	danger
1	A1	Flag		IMAGE		community	ethnicity
1	A1	Vacant lot		TEXT			
				VIDEO AUDIO			

Figure 7.6 CAQ-GIS design

shown on the left side of the figure, consists of the imagined grid and the hybrid relational database and is used to store qualitative data and qualitative codes. The CAQDAS is shown on the right side of Figure 7.6. There I also show an example of the sort of conceptual networks that a researcher can create relating different codes (and the data to

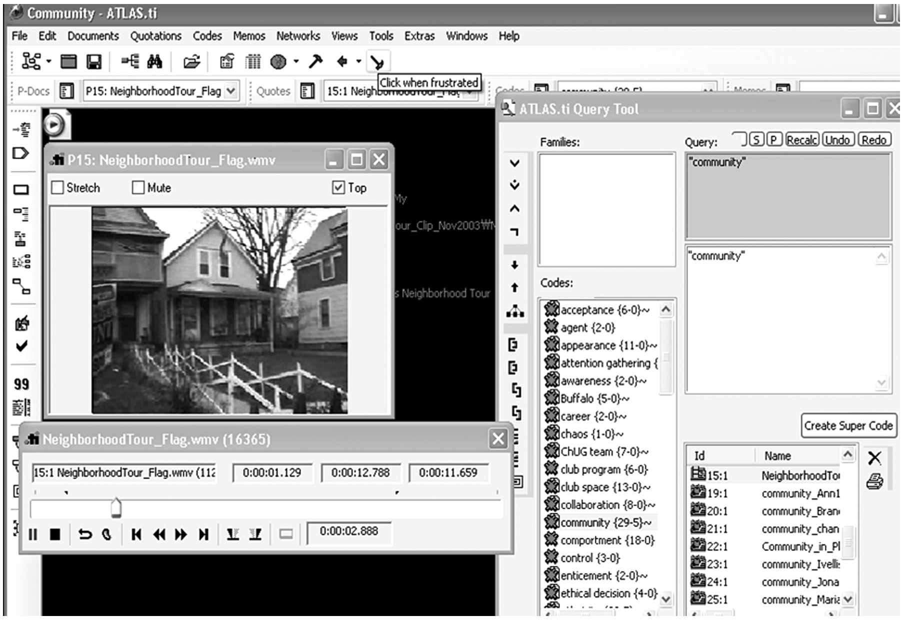


Figure 7.7 ATLAS.ti search results for code 'community'

which they are assigned). In this code network diagram, codes related to neighborhood, family, ethnicity, community, and identity are shown, along with statements that conceptualize their possible relationships with one another. In my approach, these same codes would be stored in the hybrid relational database, attached to the qualitative data stored there. Thus, in setting up a CAQ-GIS, the researcher includes a field to store codes in the GIS database. Such fields are already present in the data structures of a CAQDAS. As researchers code their data, they populate these fields with codes based upon their analysis of specific geographic entities that are represented in the GIS.

This integration of GIS and CAQDAS makes it possible to retrieve all the qualitative data stored in ATLAS.ti that is linked with particular codes, and to do the same within the GIS software. Figure 7.5 shows the result of such a search and retrieval in the hybrid relational database. From within ArcGIS, the image that was clicked had two codes linked to it in the hybrid relational database: 'code 1: house' and 'code 2: community'. A search on the same code in ATLAS.ti will retrieve all data related to that code that are stored in the ATLAS.ti database, as shown for the code 'community' in Figure 7.7. In this example, this action has retrieved several different types of qualitative data, including the video clip that is shown in Figure 7.7.

These connections between CAQDAS and GIS that are established through qualitative codes make it possible to work simultaneously with the two systems in a coordinated way. Figures 7.8 and 7.9 show the results of such a parallel search and retrieval process, based upon the codes 'community' and 'ethnicity'. For example, in my research with children about their perception of the meanings of community, I stored qualitative

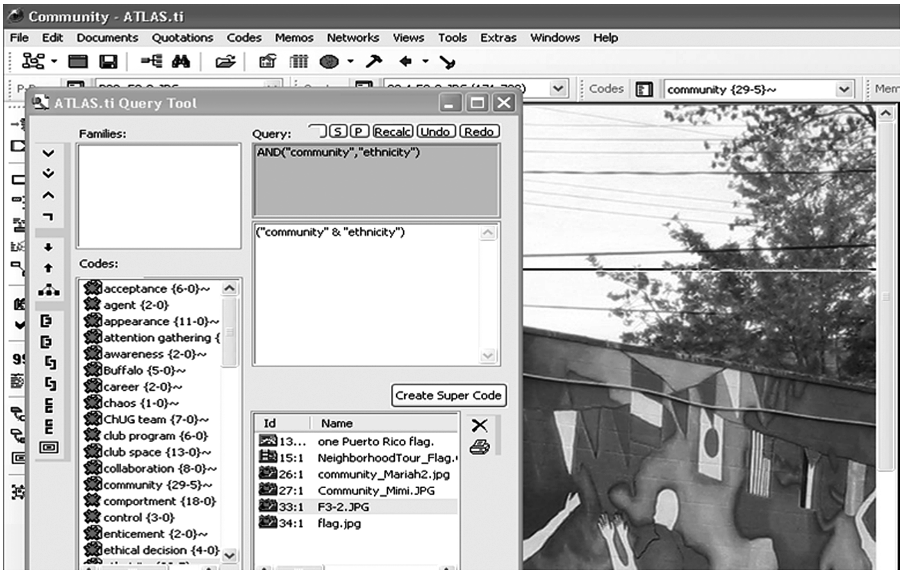


Figure 7.8 Search results for codes 'community' and 'ethnicity' in CAQDAS

data from the research in an ATLAS.ti database. I analyzed them with ATLAS.ti's network manager function, which is a very useful tool for developing and observing relationships among different codes or data. To explore possible associations between the meanings of community given by children and their ethnicity, I retrieved all data which had been coded as both 'community' and 'ethnicity' using ATLAS.ti's query tool. This action retrieved six data items: one text file, one movie file, and four images. The screenshot shown in Figure 7.8 displays some of these items as they were returned by the query in ATLAS.ti.

A parallel query executed in ArcGIS with these same codes will retrieve all qualitative data in the GIS database that carry the same code. Figure 7.9 shows the results of such a query when it is carried out in ArcGIS. The highlighted rows in Figure 7.9 show a list of qualitative data in a GIS hybrid database, which were codes with both 'community' and 'ethnicity'. Figure 7.9 shows these records in the data table that are returned by the query (names 'flag' and 'F3–2'), as well as the georeferenced neighborhood images in the map display that would also be selected as a result.

These parallel queries and data retrievals are made possible by the qualitative codes that bridge GIS and CAQDAS. These structures enable a researcher to move interactively between the two systems, recursively exploring and analyzing data that are stored in each. With this system, researchers have available to them the rich spatial analysis and visualization tools of GIS, as well as the conceptual network tools and other grounded theory tools that are available in CAQDAS. Thus, my CAQ-GIS can support robust mixed methods research that incorporates quantitative data and qualitative data; spatial data and non-spatial data; and many modes of analysis, including grounded theory, grounded visualization, and any spatial or quantitative analysis technique that can typically be carried out in a GIS.

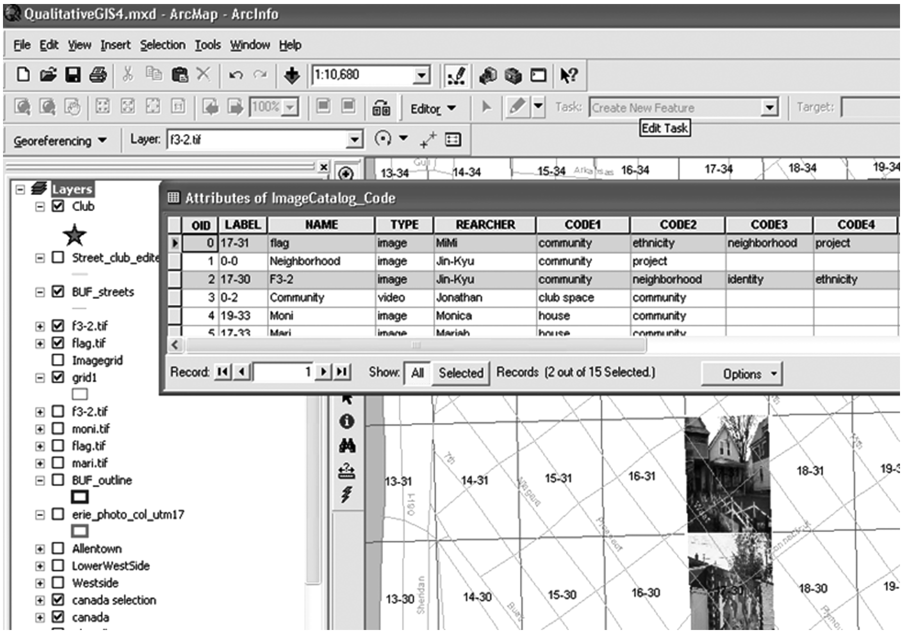


Figure 7.9 Search result for codes 'community' and 'ethnicity' in GIS

CONCLUSION

The system I have developed contributes to growing efforts by geographers and other researchers to support mixed methods research that integrates GIS with qualitative forms of data and analysis. Other existing approaches support qualitative data storage and analysis separately from GIS and its visualization capabilities. In contrast, my approach begins by georeferencing qualitative data so that they can be included in GIS data structures (and therefore in GIS-based visualization). Then, it enables researchers to carry out grounded-theory-based analysis that draws upon data stored in GIS data structures and in CAQDAS. This approach gives researchers access to the diverse analysis tools of GIS and CAQDAS in such a way that they may systematically explore multiple types of data using multiple modes of analysis.

In this chapter, I have described the key theoretical and technological concepts that inform my approach, and the software innovations I developed to implement it. First I created a way to include qualitative data directly into GIS data structures, using the imagined grid and the hybrid relational database. The imagined grid allows us to assign spatial information to qualitative data so that they can be located on a GIS-based map, and enables us to include these data in GIS. The hybrid relational database allows researchers to associate multiple qualitative data items with particular cells in the imagined grid, and gives us a way to add qualitative codes to these data. The second component of my approach is intended to facilitate inductive iterative analysis of these diverse data, through integrated use of GIS and CAQDAS. Qualitative codes, present in the data structures of both systems, can serve as a bridge connecting them. This enables systematic exploration of the data stored in each system through coordinated queries and data retrievals executed in each.

The resulting CAQ-GIS addresses many of the practical limits of other software-level efforts to facilitate qualitative GIS. Further, CAQ-GIS provides a powerful yet relatively simple solution that enables researchers to access the capabilities of GIS and CAQDAS without the necessity of re-creating either system from scratch. Such solutions are essential if researchers are to be able to adopt an integrated GIS and qualitative analysis system on any large scale. There are of course limitations to the techniques that I present here. The qualitative data stored in the GIS are still strongly structured by the requirements of GIS, such as database formats or logical query relationships that are only incidentally spatial. As well, georeferencing qualitative images to grid cells that cover large areas might confuse a user who expected data to be located based on more conventional definitions of spatial accuracy, such as precise latitude/longitude coordinates. Nonetheless, my CAQ-GIS approach shows the potential for GIS to play a valuable role in mixed methods research, not in parallel but separate practice with other methods, but in an integrated way. That is, more complex mixed methods research can be carried out with GIS than has previously been possible. Through the ability to include and analyze qualitative data *within* the GIS database, and by iteratively integrating it with CAQDAS, GIS itself becomes a mixed methods framework. I hope this development generates interest, discussion, and refinement by other researchers and practitioners seeking to break down methodological barriers and produce new approaches to support qualitative uses of GIS.

NOTES

1 The concepts of 'neighborhood' and 'community' have been debated at length in geography and elsewhere (Martin, 2002; 2003). Here I use the term 'neighborhood' and 'community' to mean those living spaces that residents identify as their neighborhood. Of course, there is a great deal of diversity in how residents identify these spaces and the meanings they attach to them, based upon their varying experiences, feelings, and social, cultural, and ethnic understandings.
2 The neighborhood image must first be clipped to match the size and shape of the grid cell.

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