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Research Article

Extending the Qualitative Capabilities of GIS: Computer-Aided Qualitative GIS

Jin-Kyu Jung
Department of Geography
University of North Dakota

Sarah Elwood
Department of Geography
University of Washington

Abstract
A number of approaches for integrating GIS and qualitative research have emerged in recent years, as part of a resurgence of interest in mixed methods research in geography. These efforts to integrate qualitative data and qualitative analysis techniques complement a longstanding focus in GIScience upon ways of handling qualitative forms of spatial data and reasoning in digital environments, and extend engagements with 'the qualitative' in GIScience to include discussions of research methodologies. This article contributes to these emerging qualitative GIS methodologies by describing the structures and functions of 'computer-aided qualitative GIS' (CAQ-GIS), an approach for storing and analyzing qualitative, quantitative, and geovisual data in both GIS and computer aided data analysis software. CAQ-GIS uses modified structures from conventional desktop GIS to support storage of qualitative data and analytical codes, together with a parallel coding and analysis process carried out with GIS and a computer-aided data analysis software package. The inductive mixed methods analysis potential of CAQ-GIS is demonstrated with examples from research on children's urban geographies.

1 Introduction

Supporting qualitative data and analysis within digital environments is a longstanding concern within GIScience, evident in ongoing research on ways of handling qualitative spatial expressions with spatial technologies (Shariff et al. 1998, Xu 2007), as well as efforts to blend GIS with qualitative research, as part of mixed methods research

Address for correspondence: Jin-Kyu Jung, Department of Geography, University of North Dakota, 221 Centennial Drive, Stop 9020, Grand Forks, ND 58202-9020, USA. E-mail: jinkyu.jung@und.edu

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practices (Pavlovskaya 2002, Cieri 2003, Kwan and Lee 2004, Matthews et al. 2005, McLafferty 2005, Kwan and Knigge 2006, Pain et al. 2006, Kwan and Ding 2008, Cope and Elwood 2009). Within these literatures, the discussion has ranged from the practical to the epistemological. Researchers have developed techniques for representing linguistic spatial identifiers within a GIS (Xu 2007), developed ways to incorporate non-cartographic data into geographic information systems (Kwan and Lee 2004, Kwan and Ding 2008), and argued that GIS may be used for the inductive exploratory modes of analysis and knowledge production that are typically associated with qualitative research (Knigge and Cope 2006; Pavlovskaya 2006, 2009).

Researchers in fields as diverse as political ecology, feminist geography, and public participation GIS have long used GIS within a mixed methods framework, often using GIS-based representations and analysis to triangulate in productive ways with other forms of evidence and analysis (Rocheleau 1995, Nightingale 2003, Robbins 2003, Jiang 2003, Weiner and Harris 2003). More recently, an emerging body of work bridging GIScience and human geography has sought to diversify the modes of representation and analysis that are possible with geographic information systems themselves. Within this emerging body of work on qualitative GIS, the central question is how the forms of evidence and analysis familiar to qualitative methods might be integrated with GIS, to produce stronger insights that if they were engaged separately. For example, how might photographs, transcripts of interviews, sketches, audio and video recordings, or other forms of evidence common to qualitative methods be integrated into a GIS? How might techniques such as coding of these data to denote particular themes or meanings associated with them be carried out in this context? More broadly, how might the inductive interpretive modes of analysis commonly understood as qualitative be handled in connection with a GIS? Existing efforts to support such qualitative data, techniques, and analysis have adopted a variety of approaches, some of which involve adapting GIS software, and others that rely upon the existing capabilities of GIS to support these capabilities (Kwan 2002, 2004; Pavlovskaya 2002, 2006; Kwan and Lee 2004; Matthews et al. 2005; Dennis 2006; Knigge and Cope 2006; Pain et al. 2006; Kwan and Ding 2008; Jung 2009).

In this article, we describe and demonstrate a related approach we call 'computer aided qualitative GIS', or 'CAQ-GIS'. CAQ-GIS brings together GIS and computer-aided qualitative data analysis software (CAQDAS), to enable researchers to take advantage of the geovisualization and spatial analysis capabilities of GIS as well as the qualitative analysis tools available in a CAQDAS. Key features of CAQ-GIS that set it apart from other efforts to integrate GIS with qualitative research include the ability to store qualitative data within the data structures of a GIS and incorporate them in spatial operations carried out in the GIS; access to the full range of data management and analysis tools of a CAQDAS; and the ability to carry out qualitative analysis practices (such as coding data) within a GIS.

CAQ-GIS relies upon a few adaptations of existing structures of GIS to support these data storage and analysis capabilities, but involves more than just these software innovations. It is also a set of research practices that involve inductive interpretive analysis of data using the representational and analytical tools of GIS and CAQDAS in concert with one another. CAQ-GIS does not perform these analyses for the researcher, but rather provides supporting tools and an epistemological framework for carrying them out in systematic and meaningful ways. While other recent qualitative GIS innovations offer new interfaces or software modules (cf. Matthews et al. 2005, Kwan and Ding 2008), our approach connects GIS and CAQDAS through the practices of research.

Just as GIScientists and others have debated whether, how, and to what ends GIS might be quantitative (Schuurman 2000), understanding the substantive and methodological contributions of various approaches to qualitative GIS requires a careful consideration of precisely how GIS might be qualitative. Thus, we begin in the following section with a discussion of multiple ways in which GIScience has engaged various understandings of how GIS might be qualitative at the level of data, analysis or representation. We emphasize two central trajectories of work: Efforts to model qualitative spatial reasoning with digital technologies, and methods-level strategies for supporting non-cartographic and non-quantitative data and interpretive analysis with GIS. In section 3, we examine the innovations through which existing methods-level qualitative GIS approaches support qualitative data and analysis in GIS. We consider their advantages and disadvantages for mixed methods research with multiple forms of data, and use this discussion to situate the methodological and epistemological goals of CAQ-GIS. In sections 4 and 5, we describe and demonstrate the key structures, functions and research practices of CAQ-GIS.

The examples through which we demonstrate CAQ-GIS emerge from a multi-year research collaboration called The Children's Urban Geography Project (ChUG).[1] This participatory project worked with university researchers, graduate and undergraduate students, an after-school program, and children from a low-income multi-racial and multi-ethnic neighborhood in Buffalo, New York. One aspect of the project involved understanding how children define their communities, and the meanings they associate with them. As part of ChUG, children painted pictures and took photographs to represent their communities, took adults to places they deemed important, and talked about their communities, creating a rich collection of multimedia qualitative evidence about their meanings of community. In the latter half of this article, we show how these data may be stored and analyzed through CAQ-GIS, in concert with more conventional GIS-based data and modes of analysis. These examples are not intended to provide a full case-based account of children's conceptualizations of community, but rather to illustrate how CAQ-GIS is performed, and how this approach for integrating GIS and CAQDAS can foster more robust insights than if either were used separately.

2 Engaging 'the Qualitative' in GIScience

Contradicting some characterizations of GIS as a quantitative research tool (Smith 1992, Lake 1993), efforts to grapple with the challenges of qualitative expressions, representations, and analyses are a longstanding part of GIScience. These engagements with different aspects of what might be considered 'the qualitative' emerge from two main areas, research on spatial cognition and data handling research, and methods-focused efforts to incorporate GIS within mixed methods research praxis. Prior accounts of qualitative GIS (Kwan and Knigge 2006, Cope and Elwood 2009) have primarily considered the latter group of approaches, so here we examine both trajectories and their contributions, to provide a fuller account of GIScience engagements with qualitative spatial knowledge, data, and analyses.

Many efforts to model qualitative spatial expressions and qualitative spatial reasoning in digital environments draw upon Egenhofer and Mark's (1995) notion of 'naïve geography' – the common sense understandings of space and spatial relations that people use to understand their surroundings. These forms of knowledge and reasoning are often non-quantitative, difficult to express in quantitative terms, and inexact or fuzzy. Egenhofer and Mark (1995) and Gahegan (1995, 1999) have advocated for development of qualitative models capable of handling these everyday human conceptions of magnitude, proximity, range, and other spatial concepts, noting the inadequacy of absolute Euclidean geometries as a means for representing the abstract, inexact, and socially situated ways that people understand the world.

This emphasis upon qualitative spatial reasoning has been taken up in many areas of GIScience, including spatial cognition research, ontologies research, and work on the digital representation of natural language spatial expressions. There is a large body of work developing and evaluating formal models for handling natural language spatial descriptors ('close', 'far', or 'beside') in a GIS (Hernandez et al. 1995, Mark et al. 1995, Shariff 1998, Shariff et al. 1998, Egenhofer et al. 1999, Mark 1999, Yao and Jiang 2005). Others have studied the cultural specificity of these qualitative spatial expressions, to consider ways that GIS might handle diverse cultural conceptualizations of space and the linguistics used to express them (Broschart 1995; Mark et al. 1995, 1997).[2] Ontologies research has also dealt extensively with qualitative aspects of language, especially within efforts to model the semantic similarity of data attributes, for integration and interoperability (Kuhn 2001, Fonseca et al. 2002, Brodeur et al. 2003, Agarwal 2005). Complementing these efforts, other scholars have developed techniques and structures for imbuing spatial data with qualitative information about the social and institutional contexts and transformations of these data (Gahegan and Pike 2006, Schuurman and Leszczynski 2006, Schuurman 2009).

These efforts to grapple with 'the qualitative' in GIScience emerge from a diverse range of applications. But they share a common concern with mediating between humans' conceptualizations and articulations of space, spatial attributes, spatial objects and relationships; and feasible mechanisms for representing these conceptualizations in the computational models of digital spatial technologies. At heart, they grapple with the complex and shifting meanings that are created and modified through human perception, in language, and in 'data', however we define it.

This same attention to the complex and multifaceted ways that people experience and understand space and place is also at the heart of methods-level efforts to integrate GIS and qualitative research practices, but the greater emphasis is upon the role of these complex meanings within the research process, and on ways of examining these meanings through multiple forms of data and modes of analysis. Within this arena, researchers have examined how data artifacts collected in qualitative research (such as text, images, and sketch maps) and the techniques used to analyze these data (such as grounded theory) might be integrated with GIS to develop richer and more robust explanations. Pain et al.'s (2006) study of street lighting and residents' fear of crime, for example, brings together focus groups, interviews, and GIS-based analysis and maps to better understand the relationship between street lighting, residents' fears, and recorded incidents of crime, an approach they call 'qualified GIS'. Pavlovskaya's (2002, 2004) study of women's household labor encodes information gathered from household interviews in a spatial database, for analysis with conventional spatial data such as location of services. Kwan (2002), Kwan and Lee (2004), and Kwan and Ding (2008) have used three-dimensional representations, time-space trajectories, and animations to incorporate personal narratives, emotions associated with spaces, sound clips, and photographs into GIS-based analyses.

In some of these approaches, 'the qualitative' means evidence gathered through qualitative methods, such as interview transcripts, field notes and observations, or sketches or photographs. For others, 'the qualitative' is rendered through forms of analysis that are usually associated with qualitative methods, such as content, discourse, or narrative analysis, triangulation among multiple sources of evidence, or grounded theory. Knigge and Cope's (2006, 2009) grounded visualization is noteworthy because it incorporates elements of both. Grounded visualization works with both conventional GIS-based spatial data and related multimedia data such as interview texts, photographs, sketches, and audio or video files; and then analyzes these multiple data in the tradition of grounded theory.

Grounded theory is a technique for generating theoretical propositions from qualitative data, through iterative inductive analysis that is meant to allow "the theory to *emerge* from the data" (Strauss and Corbin 1998). In grounded theory, researchers explore multiple possibilities or interpretations and use multiple media to represent and explore data. In grounded visualization the association between GIS and qualitative representation and ways of knowing occurs *in the analysis process*, as the researcher explores and analyzes these diverse data, to draw out recurring themes, consistent patterns, and internal complementarities and contradictions that guide interpretation of their meanings. Following other mixed methods research practices, these methods-level qualitative GIS efforts hold that while all data are partial – helpful for understanding some kinds of phenomenon, but less helpful for illuminating others – they may be woven together in ways that enable greater understanding (Creswell 1994, 2003; Lawson 1995; Dixon and Jones 1996, 1998, 2004; Gibson-Graham 2000; Tashakkori and Teddlie 2003; Johnson and Onwuegbuzie 2004; Brewer and Hunter 2006; Schuurman 2006; Elwood 2009). As well, these approaches conceive of analysis as a dynamic interplay between researchers and their data, rather than a fixed set of procedures to be executed (Strauss and Corbin 1997, 1998; Charmaz 2000; Chiovitti and Piran 2003).

Integrations of qualitative, quantitative and geovisual methods in GIS have been implemented in several different ways. Some, such as Kwan and Lee's (2004) 3-D and animated approaches or Kwan and Ding's (2008) geo-narrative approach, use modified GIS software or qualitative analysis software. Others, such as grounded visualization (Knigge and Cope 2006, 2009) or Pain et al.'s (2006) 'qualified GIS' use GIS and qualitative techniques more or less as is, and do their 'mixing' through the analysis process, working iteratively and recursively among several modes of analysis and representation. CAQ-GIS incorporates elements of both. In the following section, we examine these existing approaches for handling qualitative data and analysis, considering the strengths of each with respect to supporting the interpretive mixed methods research practices described above.

3 Existing Approaches for Handling Qualitative Data and Analysis with GIS

For scholars working to develop methods-level integrations of GIS and qualitative research, a key challenge has been that of implementation – how to associate qualitative data with GIS data structures, how to represent these data for the purposes of analysis, and how to support qualitative analysis in connection with the cartographic and other spatial analyses that GIS software are most immediately prepared to carry out. The current state of practice offers three main approaches: (1) transformation strategies that modify qualitative data so that they may be represented using cartographic techniques such as classification and symbolization; (2) hyperlinking strategies that associate qualitative data artifacts with spatial objects in a GIS; and (3) software modifications that extend the data storage or analysis capabilities of conventional GIS. For any qualitative GIS, we argue that a key priority should be retaining what is most important about qualitative research – the rich meanings that are bound up in narratives, sketches, photographs, and other data gathered through qualitative methods, while also creating ways of incorporating these data into GIS-based spatial operations. Below we assess the ability of existing qualitative GIS strategies to do so.

3.1 Transforming Qualitative Data for Geovisualization

Some scholars rely upon the visualization capabilities of geographic information systems to incorporate qualitative data. They identify spatial content within these qualitative data, then representing this content cartographically. For example, consider interviews with residents about neighborhood safety, in which they describe places where crime is rising or parts of the neighborhood they consider safe. Transcripts or quotes from these interviews contain spatial content, such as descriptions of specific places and their attributes. Or, the place where the interview was conducted may be relevant to understanding its content. These spatial dimensions of qualitative data can be represented using the geovisualization capabilities available in most GIS packages.

Pavlovskaya's (2002) research on gendered economic geographies in post-Soviet Moscow is an excellent example. Studying the multiple economic strategies employed by women to meet basic household needs, Pavlovskaya interviewed members of households about their formal, monetary, public economic activities as well as their informal, non-monetary and private economic activities. One of the ways she analyzed the interview data was through geovisualization of different households' economic activities across the study area. As shown in Figure 1 below, she aggregated and categorized the economic activities described by each household, then geolocated this information by the household's location in the city. This process transforms the descriptive text from interviews into a form that may be represented cartographically, and then analyzed with other data stored in the GIS.

Kwan and Lee's (2004) study of gendered and racialized time-space trajectories in Portland, Oregon, also demonstrates the use of geovisualization to represent spatial elements of qualitative data. Participants described their daily activities, experiences, and travels in activity diaries, and these locations and movements were represented as three-dimensional time-space trajectories in a GIS.

Using GIS-based geovisualization to represent qualitative data extends the repertoire of GIS in creative ways, expanding the roles that it might play in mixed methods research. These approaches have particular promise for broad uptake by researchers because of their accessibility and simplicity. A limitation of these approaches lies in their transformation of the original qualitative data into different forms. For example, full original narratives are not included, only those portions than can be represented cartographically, such as the location of a type of incident mentioned by an interviewee. A host of other potentially significant details are lost – how the interviewee felt, why she thinks the incident occurred, or how she altered her daily activities as a result. The essence of qualitative research lies in its efforts to systematically interpret the complicated social meanings that are produced and negotiated in data such as interview manuscripts, images

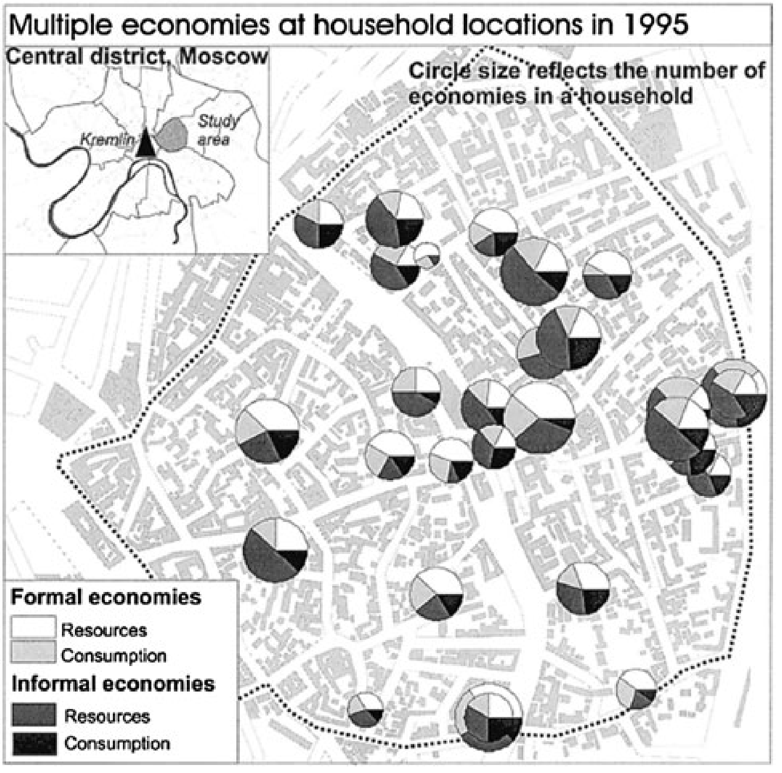


Figure 1 Geovisualizing qualitative data: Pavlovskaya's (2002) "Multiple economies at household locations in 1995"

and sketches. In the transformation of a narrative into cartographic symbols, much of the rich context that enables such interpretation is no longer accessible to the researcher as he or she is working with these data in a GIS.[3]

3.2 Hyperlinking Qualitative Data

Another way to integrate qualitative data is to hyperlink them to spatial objects in a GIS. Researchers typically use the 'hyperlink' or 'hypermedia' tools in a GIS software to link a text, a digital image, a sound file, a video clip, or any other digital file to a line, or a polygon feature. This approach is used widely, evident in multimedia cartography (Krygier 1999, 2002), multimedia GIS (Shiffer 2002), bottom-up GIS (Talen 1999, 2000), multimedia information systems (McLafferty 2005), and Matthews et al.'s (2005) use of 'hot-links'.

Cieri's (2003) research on lesbian social spaces provides an example of this approach. She collected descriptions of spaces in the city that participants identified as important social sites, and also collected GPS waypoints for these locations, hyperlinking the participants' narratives to these points. With hyperlinking, the researcher can access both the geographic object and any qualitative data associated with that object as s/he is exploring or analyzing the data. Within the GIS, the researcher can examine the points

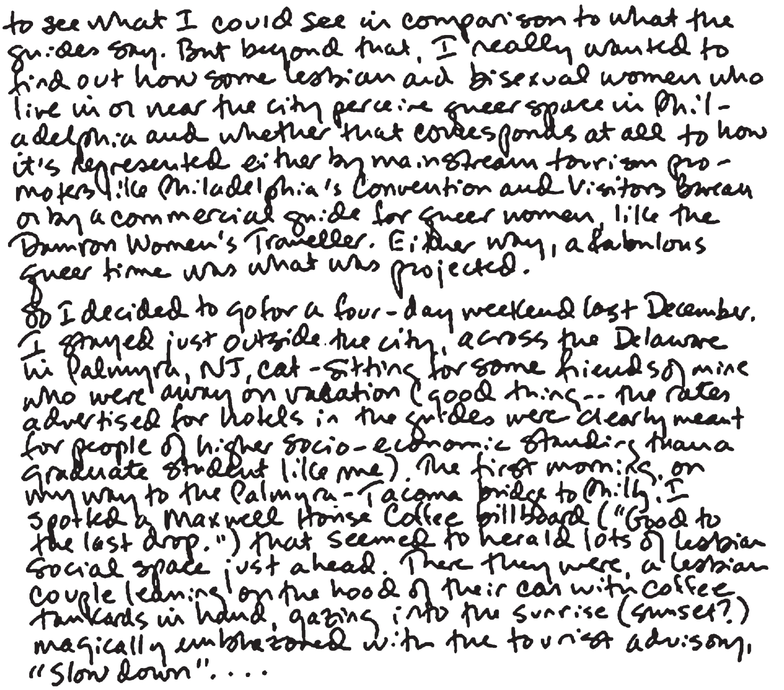
A

Figure 2 Hyperlinking qualitative data: Cieri's (2003) "Places of Interest to Gay Travelers" Map and Notes

of data collection (Figure 2a), and the original qualitative data, such as the handwritten description displayed in Figure 2b. This approach opens the door to several modes of analysis. One could examine the entire set of waypoints, to better understand some of the spatial characteristics of this community's social spaces, while also using the participants' descriptions to interrogate patterns, consistencies, and contradictions in the meanings and significance that community members assign to these sites.

Hyperlinking enables multimedia qualitative data to be associated with GIS, and enables researchers to engage the full nuance and complexity of their original data. However the qualitative data are stored separately from the spatial features, existing as digital files outside of the spatial database that contains the geographic objects. In their original form, the qualitative data do not of course carry exact locational information that would allow them to be stored within a spatial database. Nonetheless, a wider range of analysis would be possible if the qualitative data could be stored directly in GIS data structures. As we will show in our later discussion of CAQ-GIS functionalities, a spatial query executed within the GIS would then retrieve *both* geographic objects and any qualitative data that satisfied the spatial query. In this manner, a researcher could explore and analyze both conventional GIS-based data and qualitative data in concert with one another.

B



to see what I could see in comparison to what the guides say. But beyond that, I really wanted to find out how some lesbian and bisexual women who live in or near the city perceive queer space in Philadelphia and whether that corresponds at all to how it's represented either by mainstream tourism promoters like Philadelphia's Convention and Visitors Bureau or by a commercial guide for queer women, like the Damron Women's Traveller. Either way, a fabulous queer time was what was projected.

So I decided to go for a four-day weekend last December. I stayed just outside the city, across the Delaware in Palmyra, NJ, cat-sitting for some friends of mine who were away on vacation (good thing -- the rates advertised for hotels in the guides were clearly meant for people of higher socio-economic standing than a graduate student like me). The first morning, on my way to the Palmyra-Tacoma bridge to Philly, I spotted a Maxwell House Coffee billboard ("Good to the last drop.") that seemed to herald lots of lesbian social space just ahead. There they were, a lesbian couple leaning on the hood of their car with coffee tankards in hand, gazing into the sunrise (sunset?) magically emblazoned with the tourist advisory, "Slow down". . .

Figure 2 Continued

3.3 Supporting Qualitative Analysis Through Links With CAQDAS

The preceding two approaches are primarily oriented toward incorporating qualitative within a GIS, with less emphasis upon how to support modes of analysis from qualitative research, such as grounded theory, content analysis, discourse analysis, or narrative analysis. A number of recent qualitative GIS methodologies are aimed at supporting such forms of analysis, including geo-ethnography (Matthews et al. 2005), geo-narrative analysis (Kwan and Ding 2008), and the approach we describe here, computer-aided qualitative GIS (CAQ-GIS).[4] These three approaches share a common goal of associating GIS with some of the functions of computer-assisted qualitative data analysis software (CAQDAS).

CAQDAS are computer softwares that assist researchers with the management and analysis of qualitative data. They do not automate qualitative analysis but rather, provide tools to facilitate data management and analysis. Most CAQDAS allow users to store qualitative data, annotate these data with interpretive comments or 'codes' that denote particular content or meanings, and retrieve or group data based upon these codes. Some CAQDAS provide visualization tools to assist in conceptualizing relationships between data, variables, or themes. Kwan (2002) first advocated supplementing GIS with CAQDAS functionalities, arguing that both support representation and query of visual forms of evidence, enable linking to qualitative data such as photos and voice clips, and provide query tools that use Boolean operations.

Geo-ethnography (Matthews et al. 2005) and geo-narrative analysis (Kwan and Ding 2008) are built upon adapted software interfaces that extend the data storage and analysis capabilities of existing GIS. The software interface for geo-ethnography was developed for a large multi-site research project on the impacts of welfare reform. To support analysis and administration of an extremely large qualitative data set contributed by over 80 people, researchers geo-located content from interviews, field notes, and other qualitative data based upon spatial content described in these data. The geo-ethnography interface provides spatial search and retrieval tools for exploratory analysis of these geo-located data, and enabled researchers to add qualitative codes and other notes in the process of analysis. In the geo-ethnography system, the spatial database of the GIS is separate from the database storing the original qualitative data, but the interface enables researchers to access and work with both collections of data.

Kwan and Ding's (2008) geo-narrative analysis is supported by a Visual Basic extension to ArcGIS that enables coding and inductive analysis of personal narratives, oral histories, and biographies, in connection with geovisualizations of the movements of individuals through time and space. The geo-narrative system stores conventional spatial data and the narratives in its geodatabases, and can also store digital images, field notes or audio clips. Their extension to ArcGIS, called the 'space-time coder', enables the user to code these data based on concepts or variables from the research (in their example, emotions), spatial references to spaces in the study area, or temporal references to specific dates or times of day. Demonstrating their system with data gathered from Muslim women in Columbus, Ohio, about their experiences following 9/11, Kwan and Ding (2008) show its capacity to support robust inductive analysis, exploring the women's emotional geographies following the event, and its impacts upon the spatial and temporal dynamics of their daily lives. They note that this system supports more nuanced and detailed analysis than was possible with the geovisualization-based approaches used with these same data in Kwan and Lee (2004).

The software-level adaptations that support geo-ethnography and geo-narrative analysis hold great potential for harnessing the qualitative data management and analysis strengths of CAQDAS and the spatial analysis and representation strengths of GIS together in productive ways. Our approach, CAQ-GIS, supports some of these same integrations. But it introduces new innovations that further extend the analytical strengths of geo-narrative analysis and geo-ethnography. Kwan and Ding (2008) note that their new ArcGIS extension does not have all the functionalities of a full-fledged CAQDAS, a limitation that CAQ-GIS is intended to remedy. The geo-ethnography system uses a fully-functional CAQDAS, but partitions the project, with geospatial data stored in the GIS and qualitative data managed through the CAQDAS. In both systems, there is some degree of separation at the analytical level, with the GIS primarily used for spatial analysis and geovisualization, and the qualitative analysis carried out separately in the CAQDAS or software extension.

We contend that if this separation can be bridged, researchers can carry out more nuanced exploratory analysis of different forms of qualitative and spatial data simultaneously, gaining new insights through examining these different data together, in relationship with one another. If a spatial query executed in the GIS retrieves geographic objects that fit these parameters *and* qualitative data artifacts associated with those spatial parameters, the researcher may engage all of these data in relationship to one another. If a researcher annotating qualitative data artifacts with analytical codes could also annotate geographic objects with these same codes, both the qualitative data artifacts and relevant geographic objects can be included in analysis techniques that use these analytical codes. CAQ-GIS is designed to facilitate such practices.

Finally, while software developers are moving quickly to integrate commercial GIS and CAQDAS packages[5], we contend that the linkage need not be 'hardwired' through new extensions or software. If CAQDAS and GIS are used together in parallel, in a systematic process of data exploration, coding, and analysis, researchers may gain access to the full analytical and representational capabilities of each without the need for new software modules. We recognize that such softwares will certainly continue to emerge, and welcome their ever-expanding capabilities. But CAQ-GIS complements these 'hard wired' approaches, providing a more readily accessible way for mixed methods researchers to begin carrying out their own qualitative GIS integrations.

CAQ-GIS has several defining features and capabilities. It stores qualitative data directly in GIS data structures, imbuing these data with spatial information. The researcher may access these data in their original form, and can also work with these data using conventional GIS operations such as spatial queries. CAQ-GIS allows qualitative coding of both qualitative data artifacts and geographic entities within the structures of the GIS. These capabilities are implemented through the existing structures of desktop GIS software. We describe these innovations in the following two sections, with reference to analytical practices they enable.

4 Encoding Qualitative Data and Interpretive Codes into GIS Data Structures

At the level of system design, the key innovations of CAQ-GIS are its techniques for storing qualitative data and interpretive codes in the data structures of a GIS. CAQ-GIS takes advantage of untapped potential in the existing simple data models of a GIS to incorporate these important elements of qualitative research. Jung (2009) adapted elements of vector and raster data models, such as attribute tables, relational databases, and grids, to support storage of qualitative data and interpretive codes. Two such modified structures, which we term the 'Imagined Grid' and the 'Hybrid Relational Database', form the building blocks of CAQ-GIS's qualitative data storage capabilities.

The Imagined Grid is a special layer where data such as photographs, sketch maps, texts, audio clips, or video can be stored. The imagined grid is separate from other layers in the GIS. Any operation that could be carried out with a conventional layer in a GIS – such as a spatial query, overlay, or selection – could be performed with the imagined grid. The imagined grid (shown in Figure 3) is a simple raster grid whose extent overlays the other data layers to be used in a given application. With this structure, a researcher can store a qualitative data artifact in a region to which this artifact is conceptually or analytically relevant (perhaps because it represents information about that region, or because it was collected in that region). In the Imagined Grid, as in any raster layer, the vertices of each grid cell have coordinates that define their geographic location. These coordinates are used to store qualitative images such as photographs in the cells of the Imagined Grid (Figure 3c). As long as the images are clipped to have the same shape as the cells of the Imagined Grid, the geographic coordinates of a grid cell can be assigned to the corners of that image. Once each digital image is geo-referenced and rectified through this process, location information has been associated with it, such that it is incorporated directly into the Imagined Grid. For qualitative data that are visual (such as images), the display of these images

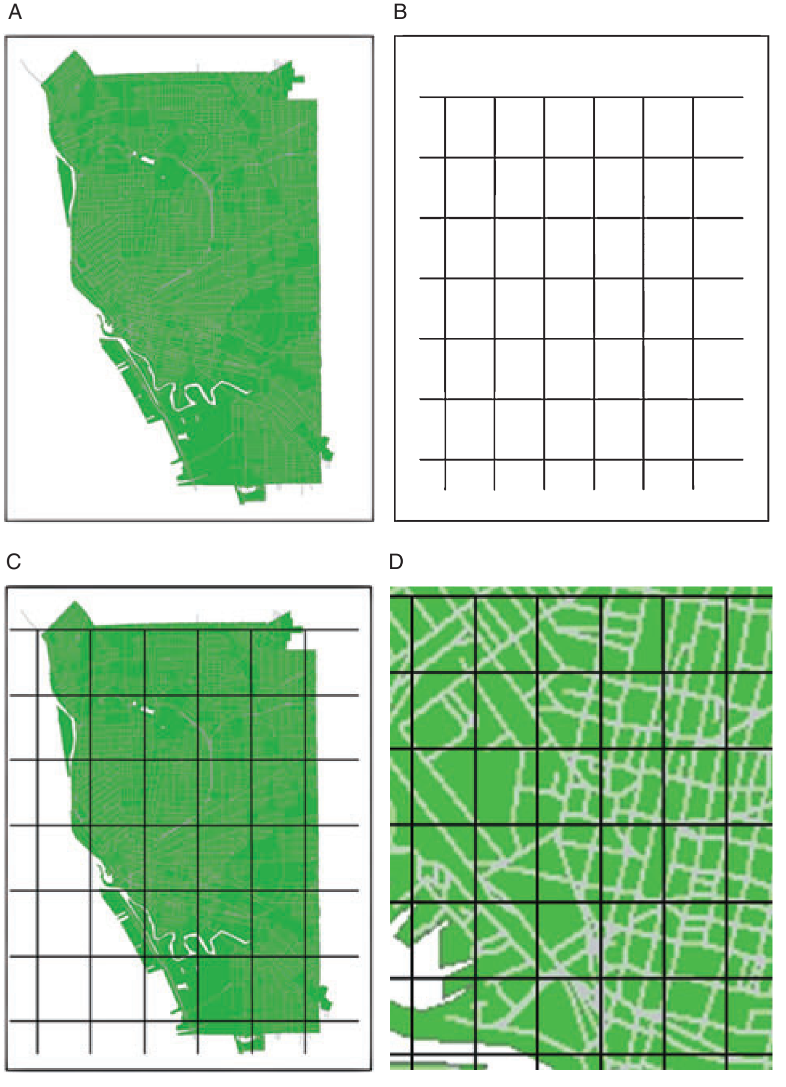


Figure 3 Structure of the imagined grid

is automatically adjusted when the map is rescaled, just like other spatial data in the GIS (Figure 3D).[6]

Figure 4 illustrates this approach with several digital images inserted into the Imagined Grid and displayed on a map. These photographs were taken by a child in his neighborhood to illustrate the meanings he associated with 'community'. The photographs were inserted into cells of the Imagined Grid, within and adjacent to the grid cell that overlaps the boy's home. When an image is stored in a cell of the Imagined Grid, it is not being located at an exact pair of x, y coordinates, as it would be if it were a vector-based point. When displayed, the image is of course not at the same scale as other visible layers. The purpose of the Imagined Grid is to associate qualitative data with areas to which they are relevant for the purposes of data storage and analysis, such as the place

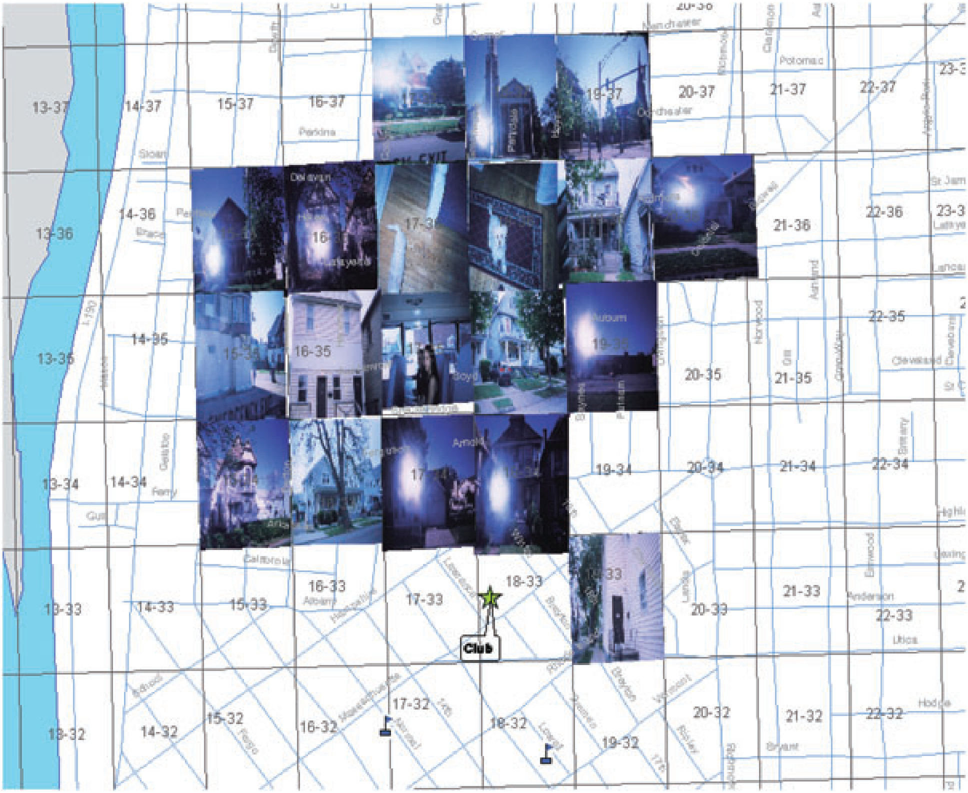


Figure 4 Visualizing qualitative images in the imagined grid

where a photo was taken, the neighborhood represented in a child's drawing, or the area which an interviewee discussed. Sound files, textual data, or video clips can also be stored in the Imagined Grid, but only visual media such as photographs or sketches may be visualized in the Imagined Grid. Again, we emphasize that the Imagined Grid is not solely intended for visualization. Rather, storing data in the Imagined Grid gives them a spatial identifier, such that they will be manipulated by any spatial operations carried out in the GIS. Rather the goal is to incorporate qualitative data into a GIS *with spatial referencing information*, so that they may be examined in concert with more conventional forms of GIS-based spatial data, such as census-based demographic data, urban infrastructural data, or air photos. For these purposes, it is not necessary that all data be visualized at exactly the same scale, nor that qualitative data be associated with a single point or pair of coordinates describing that point location.

While the Imagined Grid does allow qualitative data to be stored in the GIS and geo-located, as in any raster grid, each cell can store only one item.[7] It would not be possible, for instance, to store both an image and an interpretive code or comment from the researcher. One could not link a child's drawing with a snippet of interview transcript in which the same child explained the drawing, or include researchers' field notes, codes assigned in the course of qualitative analysis.

To support such functionalities within CAQ-GIS, we use a relational database structure called the "Hybrid Relational Database" to associate these additional data and

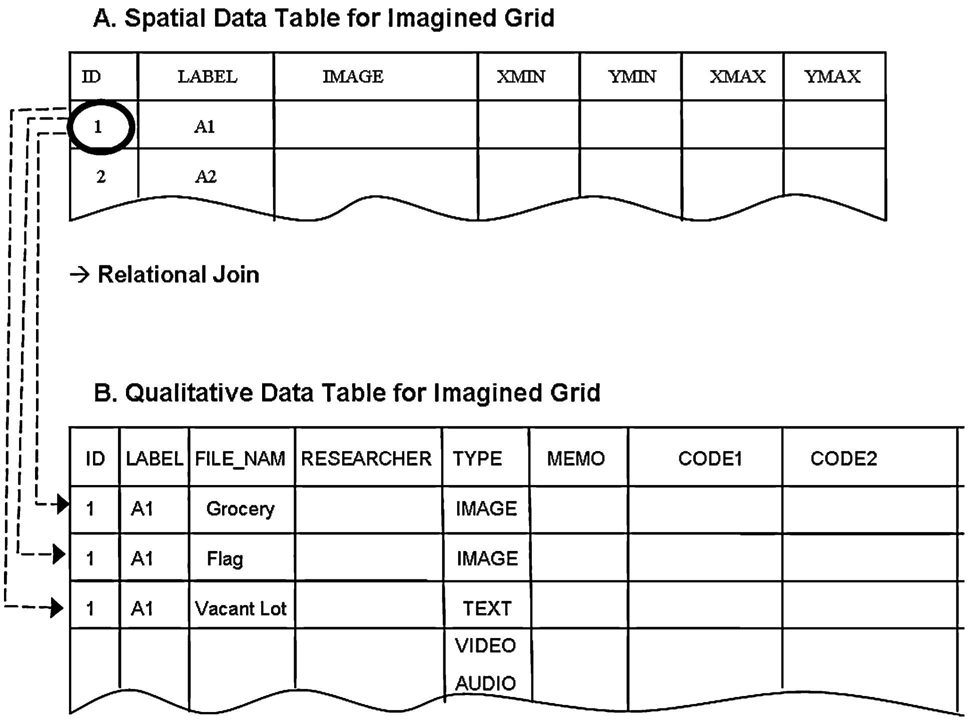


Figure 5 Hybrid relational database

codes with the Imagined Grid. Like any relational data structure, the Hybrid Relational Database allows 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 5, the Hybrid Relational Database is comprised of an Imagined Grid (identified as the 'Spatial Data Table in the Imagined Grid' in Figure 5a) and a relational table associated with it (identified as the 'Qualitative Data Table for Imagined Grid' in Figure 5b). The Qualitative Data Table is an ordinary attribute table that can store multimedia qualitative data such as images, text, audio, or video. The Qualitative Data Table can also contain interpretive codes added by researchers as they analyze these data. As shown in Figure 5b (in the columns labeled 'CODE1' and 'CODE2'), a researcher could add additional fields (columns) in and populate them with interpretive codes. Because we rely on a relational database structure, multiple records from the Qualitative Data Table may be associated with a single grid cell in the Imagined Grid. This structure is "hybrid" in several ways: it can incorporate qualitative and quantitative data, multiple media formats, and original data as well as interpretive information added during analysis.

With the structures and functions described above, CAQ-GIS can support grounded visualization and other inductive analysis practices, working with multiple forms of data. To demonstrate these capabilities, Jung (2009) stored data gathered from the Children's Urban Geography Project (ChUG), in an Imagined Grid and Hybrid Relational Database, and performed some coding of these data to illustrate the analytical possibilities of CAQ-GIS. Figures 6–9 are screen shots that illustrate how some of the data and coding from ChUG were stored, visualized and retrieved using the Hybrid Relational Database

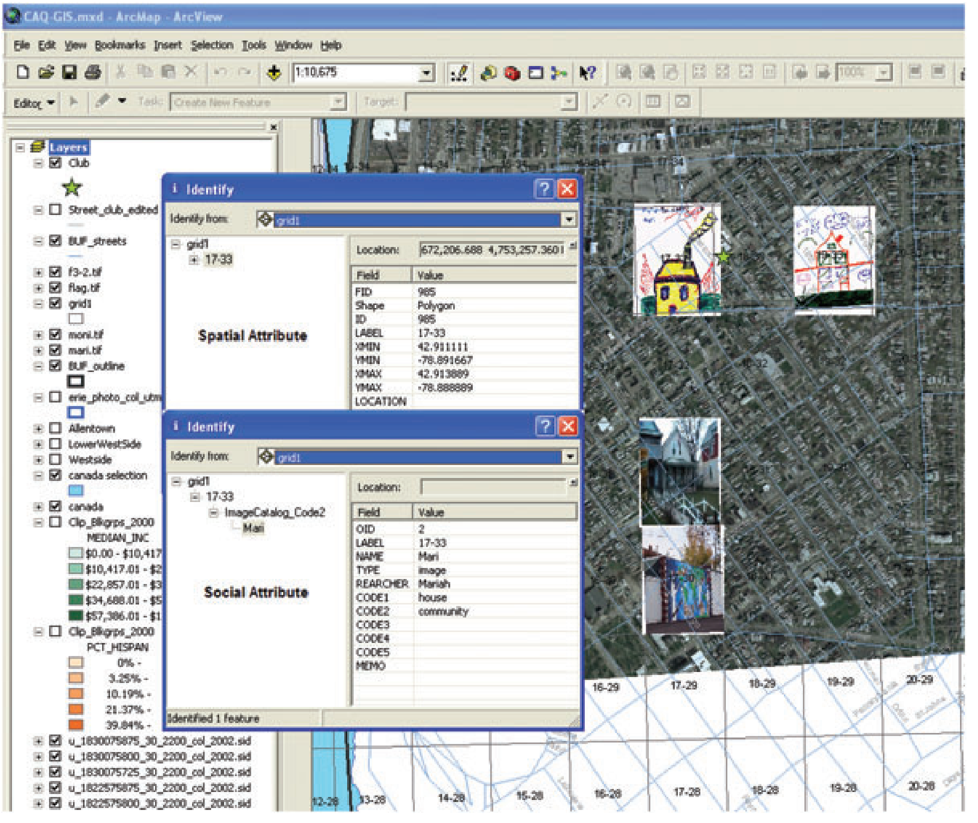


Figure 6 Retrieving data from the Imagine Grid and the Hybrid Relational Database

and the Imagined Grid layer. The data incorporated in this demonstration included conventional forms of GIS-based data used in some urban geography research, such as census data on demographics, housing characteristics and income, as well as qualitative data such as transcripts of interviews with participating children, researchers' field notes, photographs or drawings by the children, and video clips of activities led by the children. We worked with these data to analyze the children's definitions and meanings of 'community'. Was 'community' commonly defined by identities, ethnicities, neighborhood boundaries, particular institutions or establishments? What material spaces did the children identify as important to their community and choose to photograph or draw? What meanings or feelings do they associate with the concept of community? In particular, we sought to examine whether additional insights about children's geographies might be gained through the integration of GIS and qualitative research practices in CAQ-GIS.

Figure 6 shows how some of the ChUG data informing these questions were stored in the structures of the Imagined Grid and the Hybrid Relational Database. On the right side of this figure, two paintings and two photographs by the children are displayed. To the left, the uppermost window labeled 'Identify' shows the 'spatial attributes' assigned to one of the paintings – the geo-referenced information that defines its location when stored in a cell of the Imagined Grid. The fields XMIN, YMIN, XMAX, and YMAX

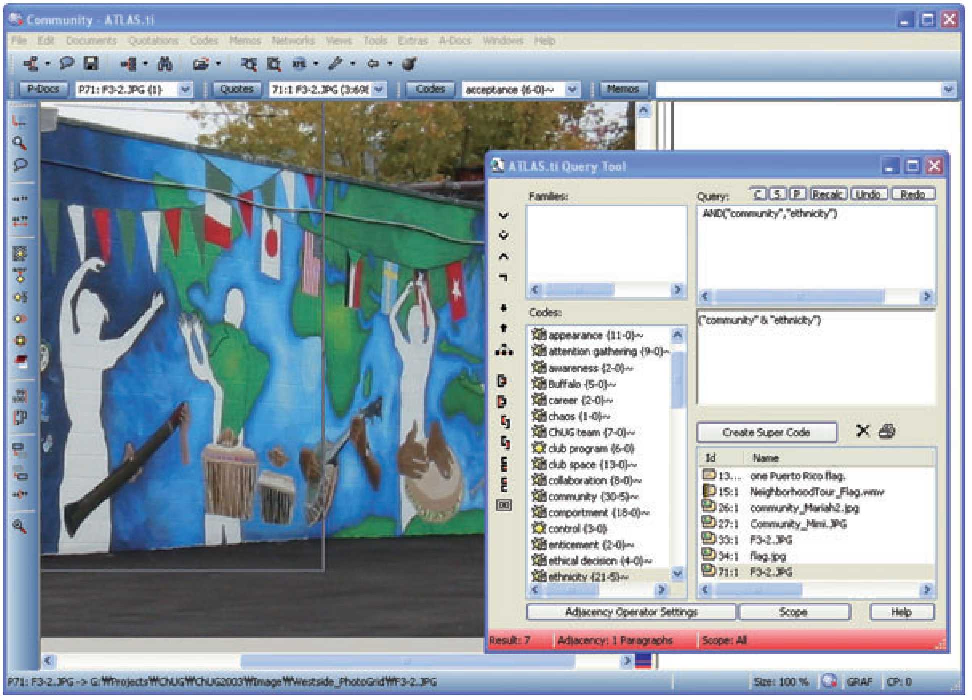


Figure 7 ATLAS ti query result for codes 'community' and 'ethnicity'

define the latitude and longitude of that grid cell. The window immediately below (also labeled 'Identify'), shows the 'social attributes' that have been associated with this painting during the analysis process – the qualitative data that were stored in the Hybrid Relational Database and relationally joined to this painting.

In this instance, the selected record includes information about the child who painted the image (Mari), the researcher who entered the data (Mariah), type of data (image), and codes added in analysis. The codes 'community' and 'house' indicate that the child's painting was created to show her sense of community, and also that she has represented the meaning of community by painting a house. The field 'label' contains a unique identifier for the cell of the Imagined Grid where this image is stored. This unique identifier is used for the relational join between the grid and the Qualitative Data Table.

With these data and accompanying codes stored in the structures of CAQ-GIS, a number of exploratory analyses are possible. Images stored in the Imagined Grid may be displayed atop other layers of the GIS, to examine associations between them. The children's photos and paintings could be displayed over thematic maps of census data on median income, to consider whether children living in areas of different socio-economic status represent community in different ways. A researcher could retrieve all qualitative data stored in the Imagined Grid with the code 'ethnicity', to examine whether the images that identify community as defined by ethnicity are concentrated in a particular part of the city. Because the researcher can work with the original qualitative data, s/he can explore multiple associations or meanings produced by these data. The children's paintings of houses in Figure 6 may reveal, on the one hand, that these children define their community based on where their homes are. Yet these paintings may also reveal

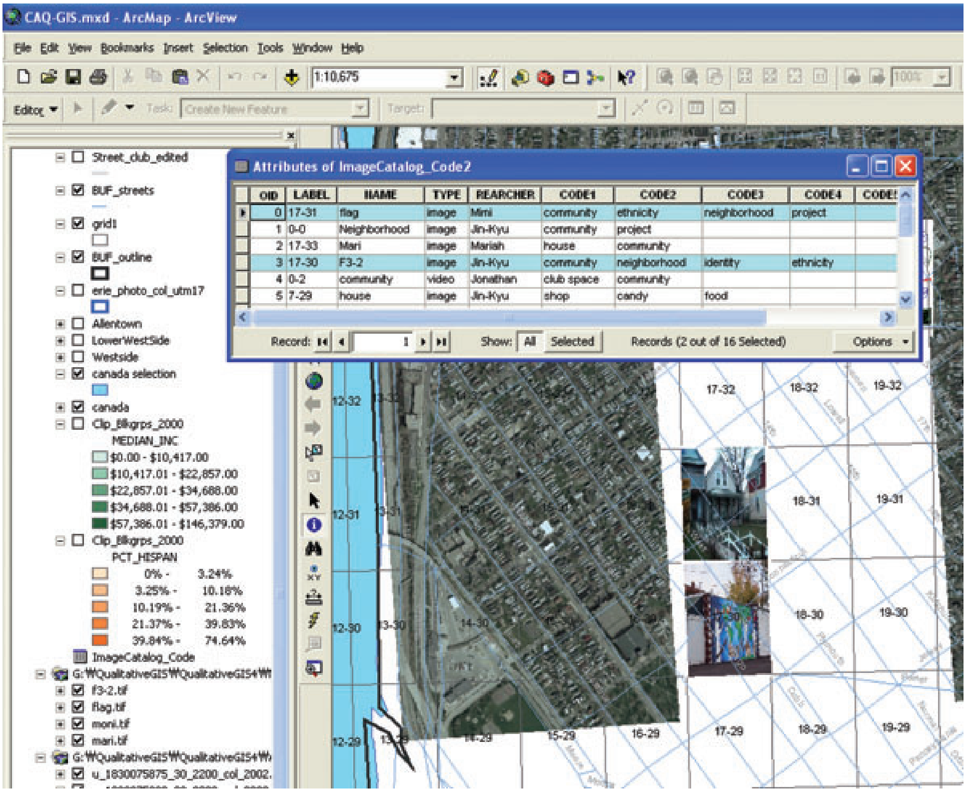


Figure 8 GIS query result for codes 'community' and 'ethnicity'

something about what these children hope or wish for their communities, as we see lush trees and yards in the paintings, in an inner city neighborhood that has relatively little green space compared to other parts of the city.

Thus, the structures of CAQ-GIS support the exploratory analysis of conventional GIS-based spatial data and multimedia qualitative data in concert with one another. Researchers may use spatial queries or attribute queries to retrieve both forms of data, visualize different layers in combination with one another, or carry out formal spatial overlays of these data. The structures of the Imagined Grid and the Hybrid Relational Database are intended to support the systematic recursive geovisualization and query that are fundamental to Knigge and Cope's (2006, 2009) grounded visualization technique. However, in the GIS-based structures described here, only a limited range of qualitative data storage, management and analysis functions are available, compared to most CAQDAS packages. Thus, a crucial element of the CAQ-GIS approach involves using its GIS-based functionalities in parallel with a CAQDAS package. We describe these linkages in the following section.

5 Linking GIS and CAQDAS through Parallel Coding and Analysis

CAQ-GIS involves not only a set of adapted GIS structures for storing qualitative data and codes, but also involves systematic parallel use of CAQDAS and GIS in analysis to

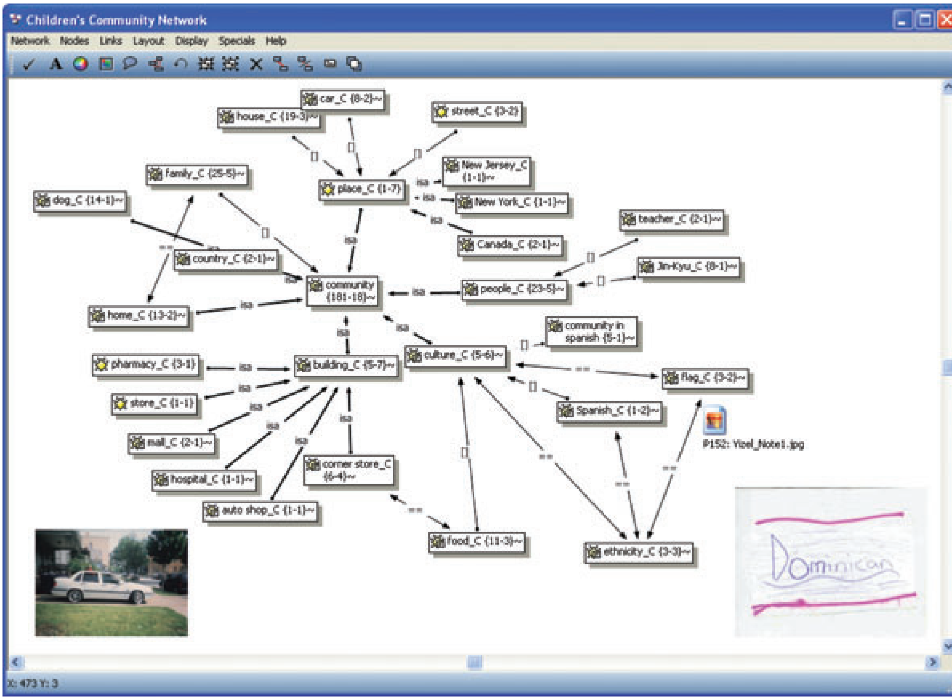


Figure 9 Network diagram of Yizel's meanings of community

harness the strengths of each. As Kwan and Ding (2008) have argued, CAQDAS packages incorporate a much richer range of tools for supporting qualitative research than can be made available in additional modules or extensions to GIS packages. Like these scholars, we take the position that the most robust integrations of GIS and CAQDAS will enable researchers to take advantage of both systems. But this integration need not be made through a software-level connection, and can instead be rendered by the researcher during data storage, coding, and analysis. In CAQ-GIS, the parallel use of GIS and CAQDAS is structured around *qualitative codes* because these codes are the heart of many qualitative analysis techniques.[8]

Codes are labels that are assigned to qualitative data artifacts, such as images or textual narratives. They may identify key themes or variables within a project's conceptual framework, such as race, gender, or inequality. Or codes may be specific words contained in the data themselves, such as instances of the word "fair" or "justice" in the responses of interviewees in a project about environmental justice. Creating and assigning codes is a form of inductive data analysis because it involves identifying key ideas and repeated themes, to find meanings, patterns, and relationships within the evidence (Miles and Huberman 1994; Miles and Weitzman 1996; Cope 2003, 2005). Once codes are assigned, they may be used for further exploratory analysis of the data. Codes can be used to retrieve and sort data with similar themes, which the researcher may then examine in greater detail. Codes can also serve as a sort of categorization or grouping schema that makes management of a large and complex collection of data more feasible.

CAQ-GIS is premised on the notion that because codes and coding are central to qualitative analysis, they can serve as the basis for a systematic engagement of both GIS and CAQDAS. Coding capabilities are of course already present in most CAQDAS. The adapted GIS structures we introduce as part of CAQ-GIS enables codes to be stored in the GIS as well. If the qualitative data that are stored in the GIS using the Imagined Grid and Hybrid Relational Database are also stored in a CAQDAS, this evidence may be coded in both systems as the researcher carries out the analysis. This parallel storage, coding and exploration of qualitative and spatial data are central to deploying CAQ-GIS in research, since they enable the researcher to carry out inductive qualitative analysis using GIS and CAQDAS together.

To demonstrate this approach, Jung (2009) used a CAQDAS package called ATLAS ti. Within an ATLAS ti 'project', users can store primary documents, quotations, interpretive codes, and memos. 'Documents' may be textual files or non-textual data such as graphics, audio, or video. Jung (2009) stored data from ChUG in both the Imagined Grid and the Hybrid Relational Database, as well as in an ATLAS ti project, and then coded these data in both systems. The specific codes were developed around the material entities referenced by the children's community photographs, paintings, and comments (e.g. 'house', 'club', 'shop', 'candy'), and the concepts or meanings circulating in these data (e.g. 'ethnicity', 'culture', 'place', 'home'). Once these data were stored and coded in the GIS and in ATLAS ti, we carried out some exploratory analysis using the softwares in parallel.

In exploring the children's data, it was apparent that for many, one element of their definition of community was shared ethnic identity. This content was coded as both 'ethnicity' and 'identity', since other forms of identity were also relevant to some children's definitions of community. These codes were applied to the children's photographs and paintings, as well as interview texts and children's writings in which they mentioned these themes. The photograph in Figure 7 was taken by one of the children to exemplify her idea of community. It was coded with 'ethnicity' because of the national flags that appear in the mural, particularly the Puerto Rican flag. Taken by itself, this simple association – a mural with a Puerto Rican flag, photographed by a child of Puerto Rican heritage – offers the researcher only the coarsest insight into the production of place-based identities. But the value of CAQ-GIS lies in its potential to facilitate examination of a much richer set of associations and patterns in the data, through parallel exploration of the data in GIS and CAQDAS.

For example, Figures 7 and 8 show the results of a parallel attribute query executed in ATLAS ti and ArcGIS based on the codes 'community' and 'ethnicity'. Figure 7 displays the results of the ATLAS ti query, showing a list of the data retrieved in the lower right corner. The action retrieved a text file (a transcript comment from a child about 'one Puerto Rican flag'), a movie clip (from a video of a neighborhood tour led by the children), and JPG files of five images produced by the children (two paintings of community and three photographs). In the ATLAS ti display shown in Figure 7, one of these photographs is displayed.

In Figure 8, we see the results of the same query carried out in ArcGIS and applied to the relationally-linked Imagined Grid and Hybrid Relational Database. Here the query has retrieved two of the children's geo-located photographs stored in the Imagined Grid, as well as the two paintings (though the latter are not visible in this screen shot). Within ArcGIS, we can access the Qualitative Data Table that is joined to the Imagined Grid, to view all information that has been linked to the records retrieved. This table is shown Figure 8, in the open window 'Attribute of Image Catalog_Code2'. This retrieval operation within the GIS could enable a number of other interpretations or explorations of the data. When the operation described above is carried out within the GIS and the resulting selections are displayed in the map interface, the researcher may discern spatial patterns, such as a concentration of artifacts coded as 'community' in a particular part of the study area. Or the researcher might further consider the relationship of the retrieval results to data stored in other layers, such as the median income layer shown in Figure 8.

Such parallel queries are valuable for robust qualitative GIS because they open the door to a much richer exploration of *all* data related to a specific theme, and because they allow researchers to develop explanations about this theme through multiple modes of analysis. Related to our example of associations between community and ethnicity in ChUG, we could use CAQ-GIS structures and techniques to explore a number of questions related to the artifacts retrieved in these operations. We might examine these artifacts in more detail, in comparison with one another, to ask whether the children identify 'ethnicity' and 'community' in reference to the same or different institutions and types of places. In their photographs or drawings, do they use different symbols and referents to identify 'ethnicity' and 'community'? If so, what might this suggest about the meanings that children attach to community, the different ways they conceive of ethnicity, or the different ways that ethnic identities may be fostered? We might further explore these qualitative data in combination with other data stored in the GIS, such as the median income data or demographic data shown in the left-most column of Figure 8, perhaps to better understand the socio-spatial contexts in which these children's urban geographies are produced. For example, do children living in higher and lower income areas of the city represent community and ethnicity differently? If so, what might this suggest about the different experiences and opportunities through which these associations are produced?

Because CAQ-GIS incorporates a full-fledged CAQDAS, we might also make use of its visualization tools, such as ATLAS ti's conceptual network diagramming functions. With this function, researchers can relate different codes (and the data to which they are assigned) to one another, using statements that conceptualize their possible relationships. Figure 9 shows a conceptual network diagram constructed from the codes assigned to data created by a child participating in ChUG.

This network diagram is centered on the code 'community' and connects it to other codes that emerged in the analysis. The connections between different nodes/codes in the network try to articulate relationships between them, to help better understand the child's concept of community. For example, based on this diagram, we see that for her, community 'is a' place, but also community 'is a' culture. With insights drawn from the network diagram, the researchers may return to the original data associated with a given code, to examine these artifacts in the sort of iterative analysis we described in the examples derived from Figures 7 and 8 above.

The value of CAQ-GIS lies not in the results of any single query and retrieval, or a single visualization of qualitative data, but in the rich range of explorations and analyses that are carried out with this approach. The parallel coding and parallel search and retrieval processes of CAQ-GIS are a way for a researcher to move interactively between the two systems, recursively exploring and analyzing data that are stored in each, using discourse and content analysis of written texts, semiotic analysis of visual representations, or geovisualization and other forms of spatial analysis. As such, CAQ-GIS is a framework for robust mixed-methods research that incorporates quantitative and qualitative data; spatial and non-spatial data; and many modes of analysis, including grounded theory, grounded visualization, and spatial or quantitative analysis techniques that can be carried out in a GIS environment. Admittedly, there is some redundancy in the operations that researchers must carry out, because our approach involves coding data in two systems and storing at least some of the qualitative data in both CAQDAS and in the GIS. The researcher might also find it necessary to go back and recode particular data, as new concepts or patterns emerged, though such re-coding would be expected in any long-term qualitative research effort. The goal of CAQ-GIS is less to provide the most efficient design for a qualitative GIS, than to propose some readily-accessible practices that mixed methods researchers might deploy to produce robust qualitative GIS practices that utilize the resources of both CAQDAS and GIS packages.

6 Conclusions

CAQ-GIS provides a systematic approach for extending the qualitative capabilities in GIS. It is not so much a new software structure, but a set of practices for data storage, coding, and analysis that can be performed by researchers working within a mixed methods framework. Our approach taps the unrecognized potential of GIS for qualitative data storage and analysis, adapting familiar structures such as relational databases and grids to support the storage of qualitative data in spatial databases. CAQ-GIS further involves a parallel coding and analysis process such that two already-existing powerful softwares – GIS and CAQDAS – may be engaged without the need to build new extensions or re-create the functions of either one from scratch. This technique is practically accessible for researchers who can develop skills in using both programs, but may not be prepared to do their own application programming. With this system, researchers can work with their original qualitative data throughout the analysis process, and imbue these data with spatial referents so that they may be included in any spatial operations carried out in the GIS. In these capabilities, CAQ-GIS overcomes some of limits of other commonly-used techniques for working with qualitative data in GIS.

Given our frequent mention of Knigge and Cope's (2006, 2009) grounded visualization as the type of mixed methods approach that CAQ – GIS is intended to support, a legitimate question may be the relationship between the two. Knigge and Cope have well demonstrated that grounded visualization is an incisive and important approach to qualitative GIS by itself, without any of the supporting techniques or practices that are part of CAQ-GIS. However, one of the added benefits of CAQ-GIS is that it creates a growing record of codes, network diagrams, and query results, as the researcher conducts parallel coding and analysis. Because this process is rendered through the software and databases themselves, these analytical resources can be retained for future analysis or sharing with other research collaborators. This capability is one step in supporting the sort of extensibility in qualitative research that Valentine (2006) has called for, making it possible to access the rich results of qualitative analysis later, or integrate them with other ethnographic and spatial data in a meaningful and manageable way. CAQ-GIS is only a small piece in addressing the dilemmas of 'scaling up' in qualitative research, but it provides one example of how existing software and database tools might be brought to bear in this effort.

More broadly, CAQ-GIS illustrates that it is possible to greatly expand the epistemological and analytical range of geographic information systems without re-inventing them. Nearly 20 years ago, Frank (1992) argued the merits of developing qualitative geographic information systems that could handle qualitative data on their own terms, but concluded that legacy and system design issues made it unlikely that such an alternative GIS would emerge. CAQ-GIS is motivated by a similar goal – engaging qualitative data and analyses on their own terms – but it does so through the existing structures and practices of GIS and CAQDAS, together with the integrative knowledge-making practices of mixed methods epistemologies. This approach complements and builds upon other software-level qualitative GIS innovations, and provides a relatively accessible framework that might be adopted by researchers working across GIScience and human geography.

Notes

1 For more information about the Children's Urban Geography project (ChUG), see Cope (2008a, b, 2009).
2 Broschart's (1980) work in Tonga provides rich examples of the cultural variability in how space and spatial relationships are conceptualized and articulated. In Tongan, directions depend upon the social and communicative setting of the situation described rather than on the Euclidean geometries of a person or object's position or movement.
3 We recognize that this 'transformation' is not permanent – the researcher of course can also make use of the original qualitative data in parallel with a geovisual representation of these data.
4 Jung has previously described the structures of CAQ-GIS in Jung (2009), though without the demonstration of its analysis capabilities which are included in this article.
5 Three major commercial CAQDAS programs, ATLAS ti, MAXQDA, and NVivo, are all in the process of adding GIS-type capabilities within their packages (i.e. the newly released version of ATLAS ti 6.0's *Geocoding* tool and MAXQDA's *Geo-Linking*™ tool). The CAQDAS Network Project, established in 1994 to explore technical and methodological developments in CAQDAS, recently included "GIS & CAQDAS" as a key research goal (see http://caqdas.soc.surrey.ac.uk/index.html for additional details).
6 In theory, a grid of vector points could be used to store these data artifacts and codes, and we are grateful for one reviewer's question about this possibility. However, the use of points to geolocate qualitative data artifacts would limit the options for visualizing them. And it may suggest that a particular artifact is somehow associated with an exact location, which may not be the case.
7 Of course, one could create multiple Imagined Grids, but this solution is inefficient in terms of data storage and computation.
8 While we focus on software-supported coding CAQDAS here, it is important to recognize that researchers have long done coding without computing technologies and many still do so. With small simple data sets, both authors prefer to code 'by hand', marking up printed texts, maps, and photographs with codes and preliminary analyses. Further, there are CAQDAS packages that are non code-based. CAQ-GIS is intended as a strategy for us with code-based CAQDAS.

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