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Qualitative GIS and the Visualization of Narrative Activity Space Data

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Abstract

Qualitative activity space data, i.e. qualitative data associated with the routine locations and activities of individuals, are recognized as increasingly useful by researchers in the social and health sciences for investigating the influence of environment on human behavior. However, there has been little research on techniques for exploring qualitative activity space data. This research illustrates the theoretical principles of combining qualitative and quantitative data and methodologies within the context of GIS, using visualization as the means of inquiry. Through the use of a prototype implementation of a visualization system for qualitative activity space data, and its application in a case study of urban youth, we show how these theoretical methodological principles are realized in applied research. The visualization system uses a variety of visual variables to simultaneously depict multiple qualitative and quantitative attributes of individuals' activity spaces. The visualization is applied to explore the activity spaces of a sample of urban youth participating in a study on the geographic and social contexts of adolescent substance use. Examples demonstrate how the visualization may be used to explore individual activity spaces to generate hypotheses, investigate statistical outliers, and explore activity space patterns among subject subgroups.

Keywords

Activity space; qualitative GIS; narrative; geographic visualization; contextual effects

1 Introduction and Motivation

There is longstanding research in the social and health sciences indicating that environmental context plays a key role in shaping human behavior, as well as attendant social and health outcomes. For example, neighborhood characteristics such as socioeconomic status and social capital have been shown to influence criminal behavior, substance abuse, mental health and psychiatric treatment, and a host of other individual outcomes (Sampson et al., 2009; Galea et al., 2005; Stahler et al., 2009). While social and health science research incorporating contextual effects is growing, as evidenced by initiatives from several federal agencies (NIH, 2011a, 2011b; NIJ, 2011; NSF, 2011), research indicates that a serious limitation of much contextual effects research is due to the exclusive focus on a subject's home location, as opposed to a more comprehensive measure of the locations and environments an individual regularly experiences throughout the movements of their daily life (Kwan, 2009; Mennis and Mason, 2011). Additionally, it is acknowledged that it is not simply the location of an individual to which an environmental influence on a social or health outcome is ascribed, but rather the interaction of the individual with their environment that is key (Cummins et al., 2007). For this reason, to understand contextual effects it is important to capture not only location, but also the perceptions, experiences, behaviors, and social contacts that occur at different locations for each individual (Mason et al., 2009).

Recently, new approaches and technologies for spatial data collection have provided social and health science researchers the ability to study how environment influences behavior in new and exciting ways, by focusing not only on the environmental influence associated with an individual's home location, but also on an individual's activity space – the locations that an individual frequents throughout their daily life. Whereas surveys and travel diaries, and technologies such as global positioning systems (GPS), support the data collection of activity space data, an additional important feature is the collection of associated data that capture an individual's experiences, emotions, and social interactions at each activity space location. For example, one such novel approach is ecological momentary assessment (EMA), which uses palm-top mobile computers to capture data about an individual's activities and feelings at the time of data capture (Shiffman, 2009), and which can be substantially enhanced when combined with location- and time-aware devices that add a georeference and time-stamp to the data capture.

Research on the environmental context of human behavior clearly shares an affinity with research in the field of geographic information science that focuses on activity space data (Golledge and Stimson, 1997), as well as recent efforts to develop approaches to integrating qualitative data and methods with GIS (Cope and Elwood, 2009). Despite these recent advances in technologies for GIS-based activity space and qualitative data capture and analysis, to our knowledge there has been little research in the geographic information science community on techniques for handling, exploring, or analyzing georeferenced, qualitative activity space data sets (with the notable exception of the work of Kwan and colleagues [Kwan, 2007; 2008; Kwan and Ding, 2008], discussed below). Because such data sets are recognized as increasingly useful for studies across a wide-variety of social and health sciences that have an environmental context component, the geographic information science community has a great opportunity, and perhaps a responsibility, to respond to this need by developing spatial techniques for representing and analyzing these types of data.

In the present study we aim to address this research need by developing and demonstrating principles of cartographic visualization for exploring qualitative activity space data. Here, we aim to illustrate the theoretical principles of combining qualitative and quantitative data and methodologies within the context of GIS, using visualization as the means of inquiry. Through the use of a prototype implementation of a visualization system for qualitative activity space data, and its application in a case study, we show how these theoretical methodological principles are realized in applied research. This theoretical discussion and demonstration of visualization-based qualitative GIS is intended to provide a way forward for other geographic information science and applied social and health science researchers who recognize the need for incorporating qualitative approaches within GIS, a technology which we note has traditionally had a near-exclusively quantitative methodological orientation.

The qualitative activity space data used in the case study capture the locations of individuals' routine activities associated with work, leisure, and other places that a subject indicates they typically visit in the context of their daily life, as well as qualitative data on individuals' perceptions, interpretations, and feelings about those places. These qualitative data take the form of brief, narrative responses to questions posed within a structured interview and are encoded as text. We describe the conceptual approach and prototype implementation of an interactive, cartographic visualization software application for exploring this type of qualitative activity space data, which for shorthand we call the Qualitative Activity space data Viewer (QAV). As a demonstration, the QAV is applied to explore the activity spaces of a sample of urban youth participating in a study on the geographic and social contexts of adolescent substance use.

2 Literature Review

2.1 Activity Space Data

An individual's 'activity space' can be defined as the set of locations that an individual travels to on a regular basis for work, leisure, school, or other typical activities (Horton and Reynolds, 1971). It is an expression of an individual's spatial behavior, such that the geometry of the activity space can be used to infer the area within which an individual spends most of their time, as well as the places where an individual may choose to frequent (or, alternatively, frequents by necessity). Consequently, the activity space provides a spatial summary of the place characteristics to which an individual is exposed (Golledge and Stimson, 1997). Activity space data can also be used to infer the spatial and temporal constraints on an individual's movement, and thus exposure to environmental hazards, accessibility to amenities, or social interaction (Kwan, 1998; Miller, 2005; Sherman et al., 2005).

Activity space data may take the form of a 'space-time path,' a set of spatio-temporally referenced points that tracks an individual's movements over time within a 'space-time cube,' where two dimensions of the cube capture planimetric position and the third dimension captures time (Hagerstrand, 1970; Miller, 1991). Such space-time path data may be captured using a travel diary, where a subject records his or her daily movements throughout the day (Axhausen et al., 2002), or using GPS and related technologies that allow the continuous, or systematic, tracking of location over time, and consequently movement (Rainham et al., 2008; Wiehe et al., 2008).

Activity space data may also be collected through surveys and interviews, where respondents are asked to recall the locations and visitation time characteristics of their daily or regular activities (Mason et al., 2009; Sherman et al., 2005). Unlike activity space data that are expressed as space-time paths, activity space data captured by surveys and interviews are often expressed as a set of locations with temporal attributes, such that each location may be attributed with information as to how often that location is visited, or the time-of-day or day-of-the-week that that particular place is typically visited.

Several approaches have been proposed for the visual exploration of activity space data. Frihida et al. (2004) describes a data structure and query template for the encoding and analysis of space-time path data. Here, an individual space-time path is visually displayed using both a ‘time-path,’ expressed as a table of chronologically ordered locations with beginning and ending times, and a ‘space-path,’ expressed as a map containing a set of locations with their chronological order of visitation indicated by a label. Such an approach has been extended by incorporating three-dimensional visualization approaches, where the spatial and temporal ‘geometry’ of a space-time path can be displayed within the space-time cube, or what has been called the ‘space-time aquarium’ (Hagerstrand, 1970).

Kwan and colleague (Kwan, 2000; Kwan and Lee, 2003) demonstrate an interactive three-dimensional, GIS-based visualization environment for exploring space-time paths. Because the simultaneous display of multiple space-time paths can be visually overwhelming, it is advantageous to be able to select certain subsets of individuals’ space-time paths to visualize while suppressing the display of others. For example, in a sample of the space-time paths of many subjects, one may select only those space-time paths of subjects of a certain race, ethnicity, or gender. In addition, color may be used to represent different activities that occur at particular places, in order to show the temporal character of different types of activities. Other examples of this approach are described by Shaw and colleagues (Shaw et al., 2008; Shaw and Yu, 2009), who describe an application which supports the visual and geometric analysis of space-time interaction across multiple space-time paths, as well as Kapler and Wright (2004).

Other approaches to visualizing activity space data focus on summarizing the activity pattern of an individual. Standard approaches include display of the mean center, standard distance, convex hull, and standard deviational ellipse of a set of an individual’s activity space locations (Ebdon, 1988; Yuill, 1971). These approaches have been incorporated in several visualization applications. For example, Buliung and Kanaroglou (2006) develop an interactive GIS-based application that supports the visualization of both space-time paths and summary measures such as the standard distance and deviational ellipse for the visualization of activity space data derived from travel diaries. Kernel density estimation (KDE; Fotheringham et al., 2000) has also been used to visually summarize the concentration of activity space locations across space (Kwan, 2000; Schonfelder and Axhausen, 2003), where the KDE acts to visually smooth the point distribution and yield a continuously varying visual field to suggest regions of relatively dense, or sparse, activity space locations or activities of a certain type.

Schonfelder and Axhausen (2003) also describe a summary measure of activity space called the shortest path network, which is a measure of the length of the shortest paths along a road network connecting the home location to the other activity space locations. The shortest path network is then visualized and quantified by buffering the network in the map display. Miller and Bridwell (2009) develop visualization strategies for representing space-time prisms, i.e. regions of possible accessibility given an individual's activity space, under conditions of varying travel constraints through a network or medium (Miller, 2005). Here, spatio-temporal regions of accessibility and areas of potential travel are displayed using isochrones, linework analogous to conventional contour lines but which are intended to display regular intervals in travel time rather than elevation. These isochrones can be displayed in a space-time aquarium setting, where a set of isochrones are used to describe a spatio-temporal region of accessibility, as well as in planimetric space, to illustrate the area of potential travel. While not focused specifically on activity space data, a related visualization approach is described by Weaver et al. (2007) in their analysis of hotel visitation over time. Here, several linked windows support multiple views on the data, including a map that displays hotel locations; tables of attributes of hotels, guests, and other data objects; an interactive interface for visualizing patterns of periodicity of hotel visitation; and a viewer for newspaper articles to coincide with dates of guest visitation.

2.2 Qualitative GIS

Qualitative data are not simply data that are non-numeric, but rather are data intended to provide information about the context and meaning of situations and processes under study, a level of detail and nuance which quantitative data typically do not address (Elwood and Cope, 2009). Importantly, qualitative data allow for the investigation of how knowledge is situated, or how individuals may differ from one another in their experience and interpretation of a situation. Qualitative data include a variety of types, including text-based narratives transcribed from interviews to field notes gathered from participant observation, as well as other materials that may take the form of imagery or performance. Qualitative theoretical approaches, such as grounded theory and ethnography, utilize techniques to interpret these rich contextual and meaning-laden data to reveal the nature of the contested interpretations and the processes that have given rise to them. In contrast to quantitative methods, which typically employ a deductive approach to knowledge production, qualitative methods are typically inductive in nature, where the development of theory is informed by the interpretation of observational data in an iterative manner (Cresswell, 2007).

The integration of qualitative data and methods with GIS has garnered substantial attention recently (cf. Cope and Elwood, 2009). Although GIS and qualitative approaches have historically been depicted as, in a sense, in opposition due to the legacy of the quantitative revolution (of which GIS has been regarded as a direct descendent) and its critics (Schuurman, 2000), Jung and Elwood (2010) note the strong qualitative component in several 'traditional' strands of GIScience research related to spatial cognition, ontology, and inductive analytical approaches (Mennis et al., 2000; Fonseca et al., 2002; Gahegan, 2000). The benefit of integrating qualitative methods and GIS is to exploit the strengths of the different approaches so that they may complement each other. Qualitative data can provide a much richer representation of the lived experience of individuals as compared to traditional, quantitative GIS data that are often based on directly observable characteristics that may be counted and are encoded in aggregated form (as with, for example, conventional national census data). However, such qualitative data are typically not georeferenced or put into a format or software package that supports analysis of spatial relationships. Analogously, GIS packages typically do not support the qualitative data handling and analysis functions typically found in computer-aided qualitative data analysis systems (CAQDAS). Hence, the integration of qualitative methods and GIS provides a framework for the spatial analysis of the lived experiences of individuals that was heretofore not possible.

Some researchers have approached qualitative methods/GIS integration by incorporating qualitative data and GIS as separate components that complement each other within a larger comprehensive research project (e.g. Pavlovskaya, 2004; Pain et al, 2006). More recently, approaches have been proposed that incorporate qualitative data directly within a GIS platform or computationally couple functions of GIS and CAQDAS (Fielding and Cisneros-Puebla, 2009; Jung, 2009; Jung and Elwood, 2010; Knigge and Cope, 2006; Kwan and Ding, 2008). Many of these efforts involve activity space data, as the objective of many studies integrating qualitative methods and GIS is to support the analysis of individuals' movements, activities, and emotional attachments to places. For example, Matthews et al. (2005) port ethnographic data stored in a qualitative analysis software application into a GIS application for mapping the daily activities of individuals enrolled in the U.S. welfare system.

An early and noteworthy contribution to incorporating a qualitative data analysis component within a GIS software platform is that of Kwan and Ding (2008), who aim to give spatio-temporal expression to narrative accounts of individuals' stories and reflections of their personal experiences, what the authors' term the 'geo-narrative.' A similar idea is described by Madden and Ross (2009) who demonstrate how geospatial technologies can be used to complement and enrich narrative testimonials of individuals related to issues of human rights. Caquard (2011) argues that advancing mapping technologies facilities the spatial expression of personal narratives as captured not only in qualitative research but also film, novels, and other creative works. Importantly, the geo-narrative approach supports the incorporation of emotional geographies within the framework of geospatial technologies so as to provide a richer representation of the lived experience of individuals (Kwan, 2007).

Kwan and Ding (2008) describe how CAQDAS text coding functions inspired by the analytical capabilities available within the CAQDAS NVivo (QSR International Pty, Ltd.) are embedded within the commercial GIS package ArcGIS (ESRI, Inc.). These authors show how such an approach can be used to facilitate the interpretation and categorization of information about an individual's feelings and emotions that can be georeferenced in space and time and attributed to the individual's space-time path. In related research, McIntosh et al. (2011) offer a formal approach for extracting and spatio-temporally referencing narrative database 'objects' form electronic text sources, such as newspapers. Here, spatial, temporal, and semantic content is mined from digital text to represent and encode a series of chronological events. One can imagine such an approach also applied to digital interview and survey data to capture individual experiences and emotions.

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Cartographic visualization of spatial, and temporal, data using maps and other statistical graphics, is seen to play a key role in qualitative GIS for several reasons. First, visualization has the capability to evoke and express the lived experiences of individuals, particularly when coupled with other representations that capture emotional attachments and experiences (Kwan, 2007). Second, much of the motivation for developing qualitative GIS is the incorporation of multiple data representations of a particular place or phenomenon, and many of these representations are indeed visual, such as photographs, images, hand-drawn maps, and so on (Jung and Elwood, 2010). Third, qualitative methods and visualization both recognize exploratory analysis as a key component, and particularly the idea of an iterative process of discovery where investigations using multiple data representations are expected to lead to new insights and discoveries about the phenomenon under investigation (Knigge and Cope, 2006; MacEachren et al., 1999).

While there are few examples of research that combine qualitative GIS, activity space data, and visualization (hence the justification for the present research), Kwan and Ding (2008) describe how visualization plays a central role in their research incorporating qualitative analysis functions within a GIS. These authors demonstrate the analytical power of linking qualitative data regarding feelings and behaviors with attendant activity space locations through the visualization medium of the space-time aquarium. Color is used to indicate individual's perceptions of safety throughout the activity space, where, for instance locations that were perceived as dangerous were colored red, and the lines representing portions of the space-time path were assigned different colors to indicate feelings of safety and danger. Kwan (2008) shows how such an approach can be used to illuminate geographically-embedded emotional experiences in a study of Muslim women's fear of hate crimes in Columbus, Ohio following the September 11, 2001 attack on the World Trade Center and Pentagon.

Another example is provided by Kraak and He (2009), where visualization of an individual's space-time path within a space-time aquarium is illustrated in the context of collections of photographs, videos, and other geotagged files that are often uploaded to the web for the purpose of sharing. Here, a space-time path is 'annotated' with such files, providing the opportunity for a user to retrieve such qualitative data on demand. In addition, lines representing the lifespan itself may reflect attributes of movement by altering the line color and width.

2.3 Extending Qualitative GIS to Visualization of Activity Spaces

This rich body of literature on activity spaces and qualitative GIS shows an ongoing effort from the geographic information science community and other scholarly fields to improve the computational representation and analysis of the geographic context of human experience. The conceptualization, data capture, and visualization of activity space data enriches our understanding of the environmental characteristics to which an individual is exposed throughout his or her daily life. Recent advances in qualitative GIS have shown how incorporating various kinds of qualitative data, such as narrative text derived from interviews, audio recordings, photographs, and drawings, can be incorporated and analyzed within a GIS package. Such qualitative representations of human experience add substantially to our ability to understand how individuals interact with, are influenced by, and have emotional attachments to, their environment.

These scholarly innovations in incorporating activity spaces, qualitative data, and qualitative analysis in the framework of GIS can be viewed not only as incremental advances in geographic information science but as part of a movement in mixed methods approaches to the production of knowledge (Fielding and Cisneros-Puebla, 2009; Elwood, 2009). Mixed methods approaches tacitly acknowledge that knowledge is partial and situated (Elwood and Cope, 2009) and thus seek to exploit the perspectives of various kinds of evidence to develop a more holistic interpretation than could be had by a single methodological approach. The integration of quantitative and qualitative kinds of data and methods are increasingly recognized as key to understanding how individuals interact with their environment to produce social, behavioral, and health outcomes (Cummins et al., 2007). We argue here that understanding such human-environment interaction can be supported in a GIS by incorporating not only ‘conventional’ GIS data for which an attribute is tied to a location (Goodchild, 1992), but also qualitative data that aim to capture individuals’ perceptions, emotions, interactions, and behaviors, data which can then be related to place via georeferencing of an individual’s activity space. Importantly, such qualitative data are not attributes tied to location but rather can be considered a relational condition between a person and a place.

In the present research we draw from the body of literature described above to advance the representation and analysis of qualitative activity space data within a GIS framework. Like Sherman (2005), we utilize activity space data gathered from interviews that captures the home and routine locations that an individual frequents throughout their daily life. We combine these data with georeferenced qualitative data that capture narrative responses to survey questions encoded as text, as exemplified by Jung and Elwood (2010) and Kwan and Ding (2008). And like Fielding and Cisneros-Puebla (2010) and Kwan (2008), we use cartographic visualization to represent the spatial expression of activity space data, as well as linked data capturing emotional attachments to place, within a map. The implementation of this visualization application employs the customization of a commercial GIS package for the display of activity space data, as is demonstrated by Kwan and Ding (2008) and Shaw et al. (2008).

The present research also extends this previous research in several ways. First, we combine many of the disparate approaches cited above to develop an integrated software environment for the visual exploration of qualitative activity space data encoded as georeferenced narrative text. We note that though other research has sought to integrate qualitative techniques such as text coding within GIS, here we are concerned specifically with cartographic visualization of qualitative data. Second, we employ a novel set of cartographic symbolization strategies to visually represent a variety of characteristics that may be attached to activity space locations and paths, including emotional attachments, the frequency and temporal character of visitation, as well as conventional quantitative GIS data that captures neighborhood socioeconomic status and related variables.

Unlike previous approaches that focus on the display of space-time path geometry in a three-dimensional space-time aquarium environment (e.g. Kwan, 2000; Shaw et al., 2008), we aim to visualize an individual's activity space within a two-dimensional map environment, using color, size, and other cartographic symbolization strategies to simultaneously display a variety of characteristics of the activity space. These characteristics include not only the geometry of the activity space, but also the attributes of each activity space location (e.g. the crime rate surrounding a particular location an individual frequents), as well as the characteristics that capture the relationship between an individual and a particular location, such as the length of time an individual typically visits the location and the perception of the location as safe or risky. Third, we show how the visualization application can be employed in the context of different inductive and deductive analytical tasks, such as data exploration, hypothesis generation, and the evaluation of statistical modeling results.

3 Application Domain: Qualitative Activity Space Data of Urban Youth

The QAV was developed to explore a qualitative activity space data set gathered as part of a study on the geographic and social influences on adolescent substance use. For the sake of brevity, and because these data are described in detail elsewhere, the data collection procedures are described here only briefly. For more detailed descriptions the reader is referred to Mason et al. (2009) and Mennis and Mason (2011a). Survey data were collected on 301 adolescents between the ages of 13-20 seeking treatment at a public health care center in Philadelphia, Pennsylvania, US. Inclusion criteria included English fluency and the absence of mental health disorders, as well as parental consent where appropriate.

The survey collected data on basic demographic characteristics as well as self-reported substance use involvement as measured by the Adolescent Alcohol and Drug Involvement Scale (AADIS), which yields an index variable indicating the degree of substance use (Moberg and Hahn, 1991). By design, the sample consists of approximately half substance users and half non-users. The Adolescent Social Network Assessment (ASNA) (Mason et al., 2004) was used to collect data on each adolescent's close personal contacts, including their substance use and influence to use on the subject. The ASNA uses a weighted scoring procedure that yields an index of a subject's *social network quality*, where negative values indicate increased social risk for substance use and positive values indicate increased social protection from substance use.

Activity space data were captured using the Ecological Interview, a structured interview where participants are asked to list and describe the locations they go to on a weekly basis, as well as their activities in sequential order over a typical week (Mason et al., 2004). Subjects are then asked how they perceive each of the places they listed by identifying the safest (i.e. the safest place from harm, danger, or the likelihood of engaging in risky or dangerous activities) and riskiest (i.e. the place in which the adolescent would be most likely to engage in risky or dangerous activities, cause trouble, or do illegal activities) place from their list of places. Subjects were also asked to name which of these places is their favorite, religious, or important place. Subjects were also asked when they go to each place (i.e. weekdays versus weekends, the time of day), how long they typically spend at each place, and how they get to each place from home. When they identified a location as a particular type (i.e. risky, safe, favorite, and so on), subjects were asked, 'What makes this place safe (or risky or favorite…)?' Answers were recorded as brief narrative responses for why adolescents perceive particular places in their activity space as safe or risky. All locations were geocoded using streets data provided by the City of Philadelphia. Each activity space location was also attributed with the social network quality index score based on the social contacts with whom the subject spends time with at the location. We note that one advantage of this approach to collecting qualitative activity space data is its efficiency, as compared to the more comprehensive ethnographic approach followed by Matthews et al. (2005), which required secondary extraction of georeferencing following ethnographic data collection.

Geographic data were also collected to capture characteristics of place that signify environments of risk and protection. Data indicating theorized negative influences on adolescent substance use included proximity to the nearest bar/store selling packaged beer, check cashing stores, pawn shops, and other related features as these locations often serve as the focal point for violence and disruptive behavior in distressed neighborhoods, and have been shown to be related to substance use outcomes in our own previous research (Stahler et al., 2007). We also generated density variables (arrests/km^2) to capture the concentration of various crime types (e.g. robbery, drug sale offenses), according to 2000-2002 Philadelphia Police Department data. Socioeconomic variables were also collected at the block group level from the U.S. Census, including indicators of race, poverty, educational attainment, and employment. These data were attached to each activity space location based on the block group within which each location resided.

4 Implementation

We develop the QAV through customization of a commercial GIS software platform, ArcGIS 9.3 (ESRI, Inc.), and the ArcObjects software component library accessed through the embedded Visual Basic for Applications (VBA) customization environment. The QAV utilizes three types of data objects to connect data with mapping objects (Figure 1):

1. LOCATION spatial data layer (point theme): A spatial data layer consisting of all the home and routine activity space locations. Each record in the attribute table represents a single home or routine activity location, with associated geographic variables, transportation variables, social network scores and qualitative information attached.

2. PATH spatial data layer (line theme): A spatial data layer consisting of all the shortest paths from each subject's home location to each of their associated routine locations. Each record in the attribute table represents the path to a single activity space location from the subject's home location, with the mode of transportation variable attached.

3. SUBJECT table: An attribute table where each record in the table represents a single subject with each subject's substance abuse status and demographic characteristics attached.

As Figure 1 shows, each table has a primary key (in bold and italics) that is a unique identifier for each activity space location, path, and subject for the LOCATION, PATH, and

SUBJECT tables, respectively. In addition, the LOCATION and PATH tables have Subject_ID foreign keys (in italics) that allow the relation of each of these two tables to the SUBJECT table. Such a schema allows for the selection of any set of LOCATION and/or PATH geographic features from the selection of any individual subject (Subject_ID), as well as for the query of LOCATION- and PATH-based attribute data by Subject_ID. This data organization strategy supports interactivity in the QAV, as described in the following section.

5 Symbolization and Interactivity Design

We draw from the previous literature to design a visualization application that is intended to display multiple georeferenced attributes of a subject's activity space locations, including both qualitative and quantitative properties, as well as to provide interactivity and facilitate data exploration. Multiple attributes georeferenced to the same location are represented by following Bertin's theory of cartographic visual variables (1983), where we employ color, size, position and shape to stand for different variables and their values. For example, like Kwan and Ding (2008), we employ color to represent individuals' perceptions of safety and risk throughout their activity space. And as with several other activity space viewers (Kwan, 2004; Schonfelder and Axhausen, 2003; Shaw and Yu, 2009), an interactive interface allows users to display the activity spaces of different individual users and explore particular geographic variables. Like Kraak and He (2009), the user has the ability to retrieve qualitative data associated with a particular location through user interaction. Importantly, we aim to display many different variables that depict the character of an individual's activity space, as well as an individual's relationship with each activity space location, while being careful to employ visualization strategies that do not cognitively overwhelm the viewer, and thus allow for effective utilization of the visualization for analysis.

Table 2 shows a listing of the variables displayed in the QAV and the corresponding visual components employed in the map interface. Each activity space location is displayed as a circular point symbol, where the color of the point symbol indicates the subject's perception of the activity space location (home, safe, risky, favorite, religious, or important). As these perceptions are categorical in nature, we vary the hue to indicate different place perceptions. Like Kwan and Ding (2008) we adopt the conventional uses of the color green to signify safety and red to signify risk. We use the conventional proportional point symbol (Slocum et al., 2009) to represent the ordinal variable capturing the typical length of the stay at that activity space location, where a smaller symbol indicates a shorter typical length of stay (e.g. a half hour) while a relatively larger size indicates a longer length of stay (e.g. more than two hours). This allows one to compare how long a subject typically stays at, say, the perceived safe location as opposed to the perceived risky location. The shortest path between the home and activity space location is displayed as a line, where the color of the line indicates the mode of transportation (e.g. walking or biking versus the use of a motorized vehicle).

The typical time of day and day of the week that the subject travels to each activity space location is symbolized by a smaller associated point symbol located to the above left and right, respectively, of the circular point symbol that denotes the activity space location itself.

This approach of using smaller glyphs such as clocks, calendars, and other like symbols to represent temporal characteristics is suggested by Monmonier (1990). Time of day is indicated by the presence of either a sun (daytime) or crescent moon (nighttime), while day of the week is indicated by a hammer (weekday) or bed (weekend). Multiple responses (e.g. both weekdays and weekends) are indicated by a triangle. The age, gender, and substance abuse status of the subject are indicated by a text box at the upper right corner of the map. Also indicated within text boxes are the social network quality, the type of place, and the narrative response of the subject for each activity space location.

As an example of this symbolization strategy, Figure 2 shows a map of the activity space of a 16 year-old female substance non-abuser. The specific locations and travel paths of this individual's activity space have been spatially altered in order to preserve the privacy of this individual, though the overall pattern of the activity space has been maintained. During the use of the visualization application, one would typically display the street network, as well as other available geographic data, for orientation. The gray point symbol represents this subject's home location, the red point symbol represents the perceived risky location, the green point symbol represents the safe location, the yellow point symbol represents the favorite location, and the orange point symbol represents the important location. For the favorite location, the sun symbol at the upper left corner indicates that the subject visits the favorite location typically during the daytime, whereas the triangle in the upper right corner indicates she visits the favorite location during both weekdays and weekends. Contrast this with the perceived risky location, where the hammer symbol at the upper right corner of the risky location indicates she visits the risky location typically during the weekday.

The blue lines that connect the home location with the risky, favorite, and important locations indicate this subject travels to these locations from home by motor vehicle. The green line that connects the home location to the safe location indicates that the subject typically travels to the safe location by walking or by bicycle. The proportional bar symbol on the left of each activity space location indicates the relative value of a particular geographic variable that the user selects to display. In this example, the variable indicating the density of drug sale offenses, as derived from police arrest data, is displayed. One can clearly see that the density of drug sale offenses at the perceived risky place is relatively high compared to the other locations.

Information about the type of place, associated place description, and social network quality are communicated via a text box that refers to the place. In Figure 2, one can see that the perceived risky place is a club, that the reason it is perceived as risky is that (as the subject states) "there's always someone getting shot around there" and that the social network quality is 28 (indicating that the people the subject associate with at the club exert a positive influence not to use illicit substances).

Interactivity with the visualization application is supported through several dialog boxes that allow the viewer to select and focus on particular subjects and variables, as well as fundamental GIS operations offered through the software such as pan, zoom, query, and selection. Figure 3 shows the map displayed in Figure 2 with the associated dialog boxes that support interactivity. The 'Choose an Individual' dialog box allows the viewer to select a specific subject whose activity space may be visualized. One can also choose to visualize the home location with any subset of perceived activity space locations (e.g. home and perceived risky location, home and perceived safe location, and so on). Here, one can also choose one of the 29 geographic variables to display. When one chooses a particular subject the view window will zoom in to the extent of the activity space displayed for that particular subject.

Display of the qualitative data is retrieved by mouse-clicking an activity space location, which generates a pop-up text box containing data on the type of place, qualitative description, and social network quality score. The ArcMap Table of Contents, which lists the specific data layers displayed on the left pane of the ArcMap window in Figure 3, lists each of the features displayed and reports the categorical and/or numeric data values for each of the associated (non-text) variables. The legend can also be displayed at any time to assist in the reader's interpretation of the map.

6 Demonstration

Here, we briefly demonstrate the utility of the QAV using three brief example visualizations of the adolescent substance use data. We consider these examples within the context of mixed methods research, where we combine quantitative and qualitative data and modes of analysis within a research study. We emphasize that visualization of qualitative data is not used simply in support of quantitative analysis but rather comprises a key role in understanding what the data can tell us about the behaviors and experiences of the individuals in the sample. The two approaches are meant to complement each other with the aim of generating insight that cannot be had by a qualitative or quantitative approach in isolation (Elwood, 2009).

Here, qualitative data in the form of brief narrative text is used to capture the perceptions and social relationships that an individual attaches to a particular place within his or her activity space. Quantitative data is used to capture the socioeconomic character of the neighborhoods within which these places are located. Visualization is used to depict the nature of an individual's activity space and the perceptual and social meanings an individual attaches to various places. Statistical analysis is used infer general patterns and relationships among variables that occur over the entire sample of individuals. In the examples below, we show how visualization of qualitative and quantitative data may be used as an exploratory device to generate theoretically robust hypotheses that may be tested using statistics, as well as to improve the interpretation of, and possibly validate, previously derived statistical results. These examples also demonstrate how visualization can be used to interpret the social experiences, and perceptions of safety and risk, as tied to important places in an adolescent's daily life. These interpretations can then be compared to existing theory regarding adolescent substance use to develop a richer understanding of the lived experiences of these adolescents, as well as the varying mechanisms of risk of, and protection from, substance use among different population subgroups.

6.1 Exploring Individual Subjects for Hypothesis Generation

An important data exploration approach offered by the QAV is to explore the activity space of individual subjects. The purpose of such visualization is to elicit items of quantitative and qualitative data that may be interpreted by the analyst to provide a more holistic understanding of the experience of an individual subject than may be had by looking only at data presented in summary form. For example, Figure 4 shows the activity space of a 17 year old female non-substance user. Note that the street map and other geographic data that may orient the viewer are not displayed here in order to preserve the anonymity of the activity space locations and thus to keep the confidentiality of the study subjects. Though it is perhaps difficult to see in the figure because the streets are not displayed for purposes of privacy protection, this subject's activity space is quite spread out across the city, with her home being in southwest Philadelphia and her favorite place occurring in northeast Philadelphia. A distance calculation reveals the distance from the home to the favorite place is approximately 8.5 kilometers. A cursory visualization of the activity spaces of a number of other subjects confirms that the activity space for this particular subject is unusually spatially extensive. One can also see that the density of drug offense arrests at her home location is very high compared to the other activity space locations.

A natural question would be to inquire why, unlike most other subjects in the sample, this subject travels such large distances on a regular basis. An answer may be found in the qualitative data associated with her activity space locations, which may be retrieved by clicking on each activity space. Both her favorite and important places are restaurants where she gathers with her family during the daytime on the weekends, which suggests the strong role and importance that family relationships play in her life, even if it appears she has to travel substantial distances during the weekend to maintain those relationships. Her perceived risky place is a recreation center that she frequents on the weekends during the day and night, and is also located in northeast Philadelphia. The qualitative data indicate that it is the presence of violence at the recreation center which makes it risky. Importantly, however, the social network score reveals that social influences on the subject at this risky location are very positive, and encourage the subject not to use illicit substances.

In light of this information, and in the context of the literature on the mechanisms of adolescent substance use, one can speculate on the contextual influences at work. For this non-substance using teen, the negative influence of the high rate of substance use nearby the home (as indicated by drug sale offense arrest data) is countered by 1) the presence of strong family relationships that also allow the subject regular exposure to neighborhoods with evidence of relatively low substance use and 2) pro-social influences at a place at which she chooses to spend leisure time but which she also explicitly recognizes as risky due to illicit activity.

While for brevity's sake we review the activity space of just one subject here, this example shows how the QAV facilitates quickly and easily reviewing the spatial expression, perceptions, and descriptions of subjects' activity spaces in this manner to formulate hypotheses regarding the environmental context of adolescent substance abuse. Without the QAV it would be very difficult to recognize the relationship between the routine locations a subject frequents, the environmental characteristics regarding crime and poverty of those locations, the family ties related to those locations, and the perceptions or safety and risk related to those locations, such that a coherent narrative of the contextual nature of substance use (or its absence) for an individual may be developed.

6.2 Post-Modeling Analysis of Statistical Outliers

The QAV can also be used following statistical analysis to investigate the nature of outliers, or those observations which are poorly estimated by a statistical model. Understanding the reasons why an outlier is poorly predicted can be key to interpreting model results. As an example of this we use the QAV to explore an outlier subject based on a statistical analysis of the social and environmental contexts of adolescent substance reported in Mennis and Mason (2012). This analysis uses ordinary least squares (OLS) regression to estimate AADIS (the index of drug involvement defined above) where the form of the model and the expected signs of the coefficients are given as

$$AADIS=\beta_0+\beta_1 Age+\beta_2 Male+\beta_3 Disadvantage-\beta_4 Social\_ \ Network\_ \ Quality+\varepsilon$$

and where *Age* indicates the age in years of the subject, *Male* is a dichotomous variable indicating the gender of the subject, *Disadvantage* is a continuous index variable indicating socioeconomic disadvantage (composed of poverty, low educational attainment, unemployment, and other indicators) in the neighborhood of the subject's perceived risky place, and *Social Network Quality* is the index score of social influence (as described in Table 1) at the subject's perceived risky place. As noted in Mennis and Mason (2011b), all explanatory variables are significant in the expected direction (*Age*: β=0.391, p<0.005; *Male*: β=0.162, p<0.005; *Disadvantage*: β=0.139, p<0.01; *Social Network Quality*: β=-0.274, p<0.005; R^2=0.326). While this statistical analysis supports the hypothesis that social and environmental influences at a subject's perceived risky place are associated with adolescent substance use, here we are interested in those subjects that are outliers of the model, i.e. subjects for whom the general statistical pattern does not hold. Understanding why the model estimates substance use poorly for certain subjects may indicate model misspecification or other relevant information.

We use the QAV to explore an outlier subject with a particularly high residual for the model specified in equation 1, an 18 year old substance user (AADIS=63) for whom the model estimates non-substance use and whose activity space is presented in Figure 5. The QAV reveals that a single location is identified as risky, important, and favorite. The qualitative data reveals this location to be the subject's grandmother's house, where the subject indicates that this is a place where family gathers, where the subject feels 'comfortable,' and where the subject spends time playing games. The social network quality is positive, 14, indicating that there is a strong social influence not to use illicit substances at this location. The relatively high social network quality score, coupled with the female gender of the subject, is likely what leads the model to inaccurately estimate low AADIS for this substance user. Note, however, the reason that the subject perceives this place to be risky, as indicated by the qualitative data expressed in the map – that she could 'get into a lot of trouble there…because of drug activity.' This qualitative description thus indicates that the subject has interpreted 'risky' not in terms of the presence of illicit or dangerous activities (as it was intended in the survey) but in fact as just the opposite – risky in terms of getting in trouble with her family for engaging in just such activities.

This difference in the semantic meaning of a perceived 'risky' place clearly undermines the assumptions of the statistical model for this subject, and illustrates why the social network quality at this risky place appears to have the opposite relationship with substance use as compared to the general pattern observed over the entire sample. Understanding the nature of this outlier subject lends credence to the general association between social network quality and substance use at the subject's perceived risky place, while also illuminating potential unanticipated variation in the semantic interpretation of this survey question by survey respondents – certainly an important piece of information in developing future surveys on this topic and for this population.

6.3 Exploring Activity Spaces by Subject Subgroups

We can also consider how the visualization of qualitative activity space data can be combined with more conventional GIS-based visual analysis of spatial patterns and quantitative analysis to reveal elements of spatial behavior (Knigge and Cope, 2006). To this end we focus briefly on a major research question surrounding environmental context research relating to the moderating effects of age, i.e. how contextual effects operate for different age groups. We begin by simply browsing the activity spaces of various subjects, which suggests that younger subjects have more spatially concentrated activity spaces than older subjects. For example, consider the activity spaces shown in Figure 6 for a 13 year old subject and an 18 year old subject, where the younger subject's routine locations are clustered nearby his home in West Philadelphia and the older subject's routine locations are more spatially dispersed. While Figure 6 shows only two subjects, the difference in activity space pattern between the younger and older subjects is typical.

To investigate such a pattern more thoroughly, it is useful to display multiple subjects' activity spaces simultaneously, so as to visually explore activity space patterns in aggregate. However, one of the primary challenges of visualizing multiple activity spaces simultaneously is to maintain visual clarity, such that the display is not so cluttered by symbols that visual exploration is compromised. One approach to visualizing multiple activity space patterns is to examine selected subgroups of the data, so that visual comparisons among the activity spaces of different subgroups may be obtained. We use this approach to examine the perceived risky activity space locations for four subgroups of substance users based on age: users aged 13-14, 15-16, 17-18, and 19-20. Such maps support the visual exploration of the numbers of users within each age group as well as the spatial distribution of perceived risky places within each age group.

Figure 7 show maps of the perceived risky places for the substance users within each age group category. One clearly notices first that the numbers of substance users differs among age groups, where there are fewer 13-14 year old users as compared to the older age groups. Note that there are approximately equal numbers of adolescents within each age group in the sample. Thus, these maps indicate that the percentage of substance users within each age group increases from the youngest to the oldest age group. As noted above, this is consistent with research that shows substance use is more likely among older adolescents.

The spatial pattern of risky places is also notable. At younger age groups, i.e. 13-14 and 15-16, most of the perceived risky places are concentrated in West Philadelphia, which is the section of the city where the health center is located and where most of the subjects reside. The older age groups, however, show a greater spatial dispersion in the location of their perceived risky places, where risky places occur not only in West Philadelphia but also in many other parts of the city. This suggests that the role of perceived risky places with substance use may be different for older as compared to younger users, where younger adolescents are likely to be under greater influence from their parents and older adolescents may have more freedom to travel and choose where to spend leisure time. In further statistical tests we found that, in fact, the social and geographic influence of the perceived risky place on substance use is moderated by age, where the magnitude of the influence of risky place characteristics on substance is greater for older, as compared to younger, adolescents (Mennis and Mason, 2012).

7 Conclusion

The recent growth and application of geospatial technologies such as GIS and GPS, as well as movement towards integrating GIS with qualitative methods, have facilitated progress in longstanding research questions in the social and health sciences concerning environmental contextual effects on human behavior. Yet, despite these advances in data gathering technologies and methods that facilitate the collection of qualitative activity space data that can inform contextual effects research, there are few examples of how such data may be effectively explored and analyzed. Research on health issues such as substance abuse, obesity, and other health behaviors and outcomes, as well as social outcomes such as crime and economic stability, can benefit from the collection, management, and analysis of data that capture the movements and interactions of individuals within the environments of their daily lives. The present study is intended to advance research in the theory and methodology of how these relatively new kinds of data can be represented and analyzed in GIS, and thus contribute to ongoing research demonstrating how geographic information science can inform the major social and health science questions of our day.

This research also demonstrates how georeferenced qualitative data (in this case, brief narrative survey responses encoded as text) can be combined with quantitative spatial data to better understand the lived experience of individuals, and consequently how individuals' behaviors and health outcomes are embedded within place. The demonstrations illustrate that understanding the spatial, social, and perceptual context of adolescent substance use is substantially enhanced by integrating quantitative and qualitative data representations. By simultaneously viewing the map of activity spaces, the perceptions of the different places, and the narrative and social characteristics associated with each place, a richer depiction of why the adolescent may be more or less likely to abuse substances emerges. By interpreting these visual representations of an individual's experiences and perceptions in the context of place, one can begin to understand the processes that guide behavior and health outcomes. This interpretation of visual representations is often inductive in nature, and may be combined with more deductive analytical techniques in an iterative manner to refine and develop theories of causation. Such methodological principles should be a hallmark of future developments in qualitative GIS for social and health science research. Indeed, one of our main points is that advancing research in contextual effects on social and health outcomes is dependent on combining geographic qualitative and quantitative data and approaches. Geographic information scientists have a key role to play in developing the technologies and methodologies to facilitate such research.

We acknowledge several limitations of the present research, which we consider here as avenues for future research. First, as a prototype implementation, the software environment is tailored somewhat specifically to the application domain and project data relating to urban youth. Clearly, not all qualitative activity space data sets will have the same variables as those described in the present research. We note, however, that the prototype implementation is intended to provide an example of how principles of geographic visualization may be applied to qualitative activity space data by using visual variables such as color, size, and shape, as well as text capturing qualitative data, within the framework of an interactive visualization environment. These fundamental principles may be extended to other domains to support data exploration of other qualitative activity space data sets.

Second, the qualitative data handling component is currently limited to text fragments that may be displayed easily within a pop-up call-out box. Certainly, qualitative data can include a variety of data types, including photographs and other images, as well as longer interview transcriptions or other texts. Jung and Elwood (2010) have shown how qualitative data in the form of images, sound files, video, and text can be georeferenced for retrieval and interpretation in a GIS environment. One can imagine how the prototype visualization environment presented here can be extended to include these other digital representations, where, for example, one might retrieve not only a text fragment by clicking on a location, but also potentially a photograph or a sound clip of an interview with the subject about their experience at that location.

Third, while interactivity is supported in the QAV via dialog boxes and mouse clicks that allow for the selection of specific cases and variables to be displayed, the visualization environment lacks the dynamic interaction modes and multiple linked display windows of other geographic visualization environments. For example, several visualization environments for spatial quantitative data contain multiple windows where various views on the data (e.g. maps, scatterplots, parallel coordinate plots, and so on) may be simultaneously viewed and explored through interactive modes such as linking and brushing (Andrienko et al., 2001; Gahegan et al., 2002). These devices were developed specifically for exploring quantitative data, and therefore may not be easily transferable to qualitative data simply because text and other qualitative data encodings (images, video, etc.) do not map neatly onto displays such as scatterplots and other visualization tools oriented towards the summary display of numeric measurements.

However, one can imagine a qualitative visualization system, analogous to the approach of the quantitative visualization systems cited above, with multiple windows providing different linked views on the data to support data exploration. Indeed, such an approach has already been hinted at in the work of Kwan and Ding (2008), where various windows displaying a text coding editor, activity space paths, and links to photographs are described. Knigge and Cope (2006) and Kraak and He (2009) also suggest computational frameworks for multimedia representations linked through georenferencing to support data exploration. And Weaver et al.'s (2007) visualization environment for spatiotemporal hotel visitation data not only provides visual analytics for exploring patterns of spatio-temporal periodicity, but also dynamic links to historic documents and other qualitative data. When combined with georeferencing of non-traditional GIS data, such as interviews, imagery, and video (e.g. Lewis et al., 2011), such developments hold particular promise in extending GIS-based representations and analyses of the lived experience of individuals.

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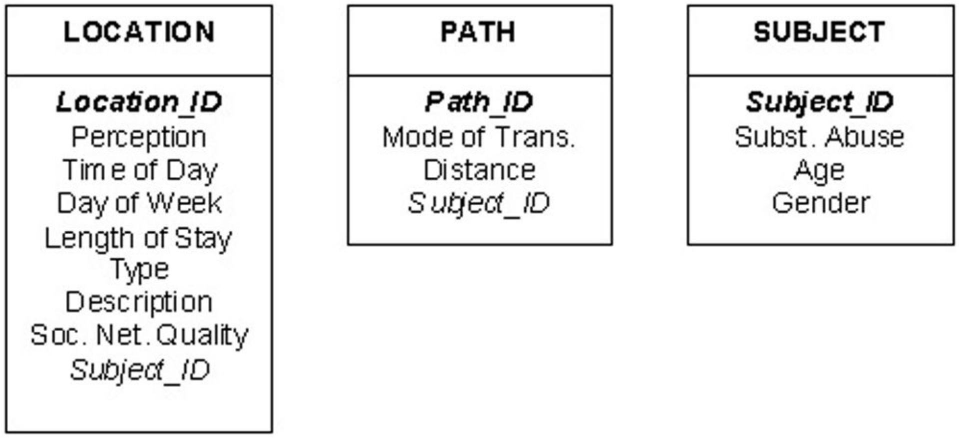


Figure 1.
Tables in the QAV, where bold indicates the primary key and italics indicates the foreign key.

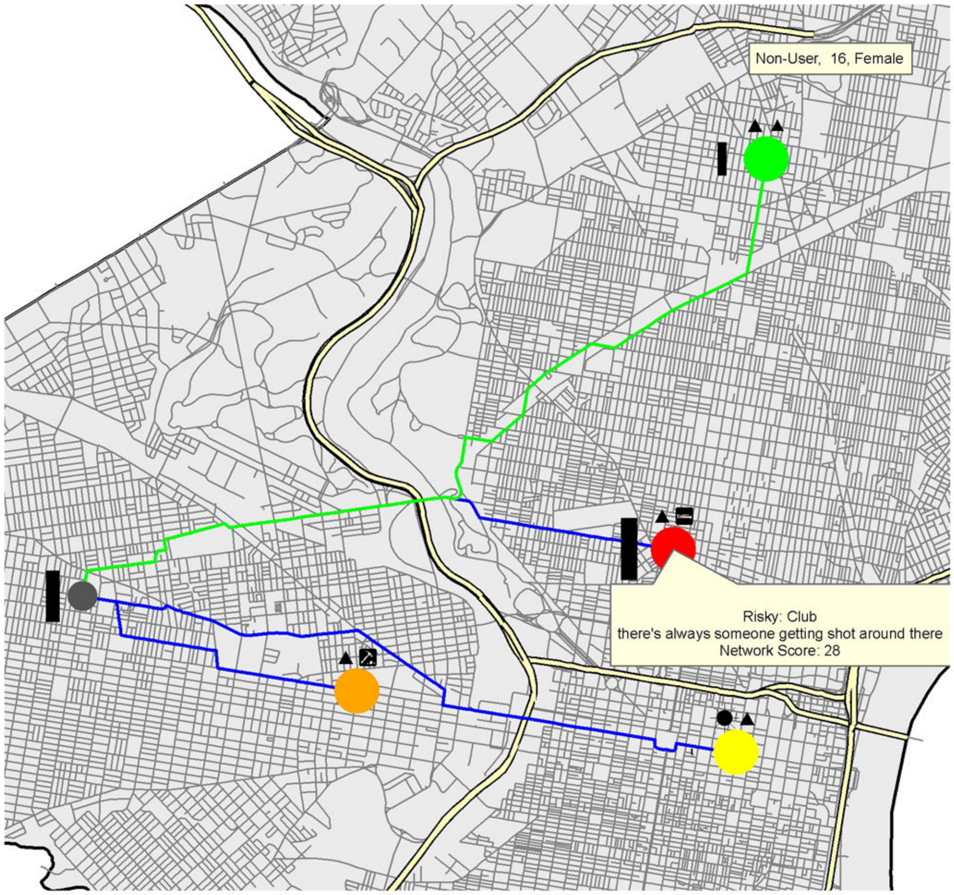


Figure 2.
An example of all the activity space locations for a 16-year-old female non-user. See text for explanation of the symbology. Note that specific locations and paths have been spatially altered for privacy protection.

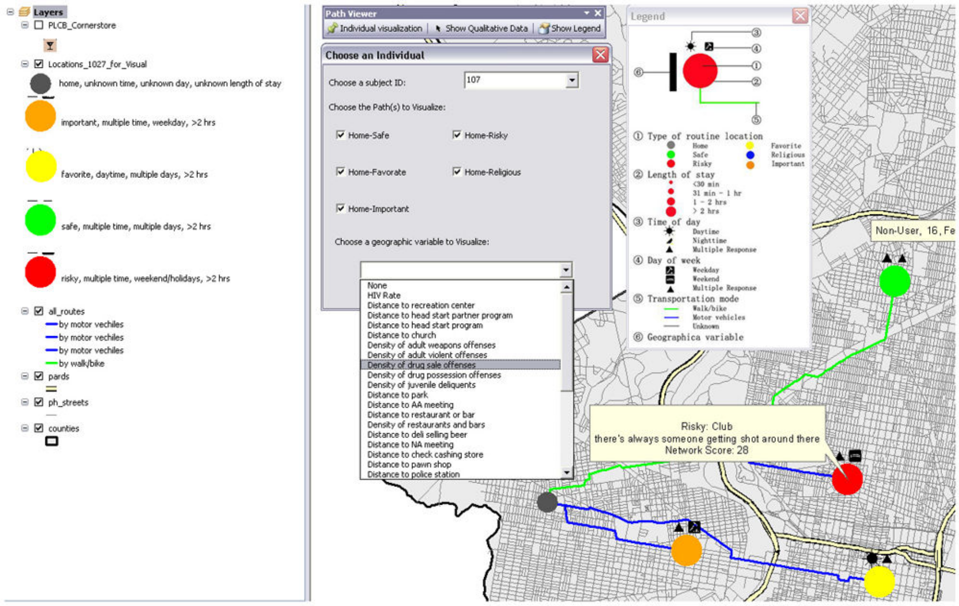


Figure 3.
Interface devices of the QAV.

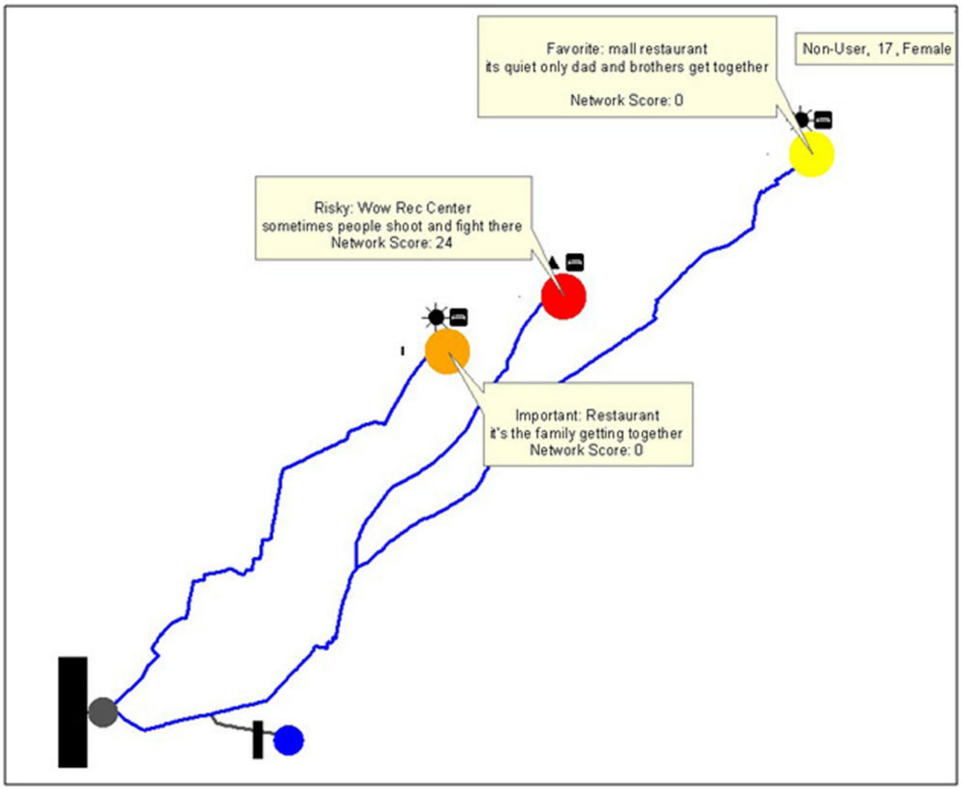


Figure 4.
Activity space map of a 17 year old, female non-substance user.

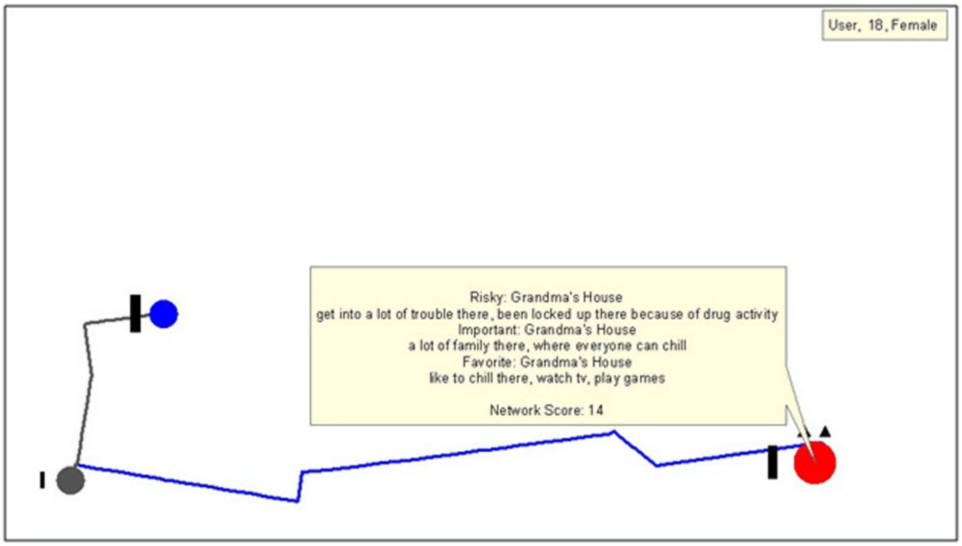


Figure 5.
Activity space map of an 18 year old, female substance user.

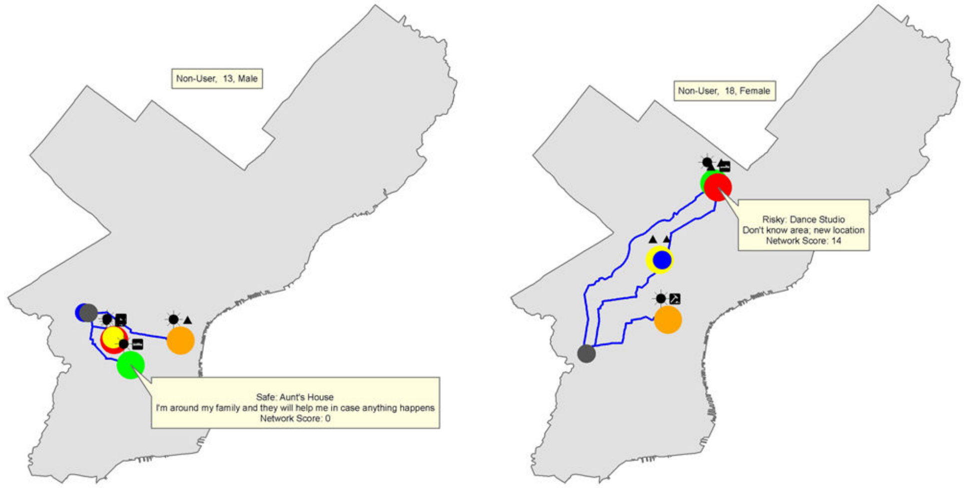


Figure 6.
Activity space maps of a 13 year old (left) and an 18 year old (right).

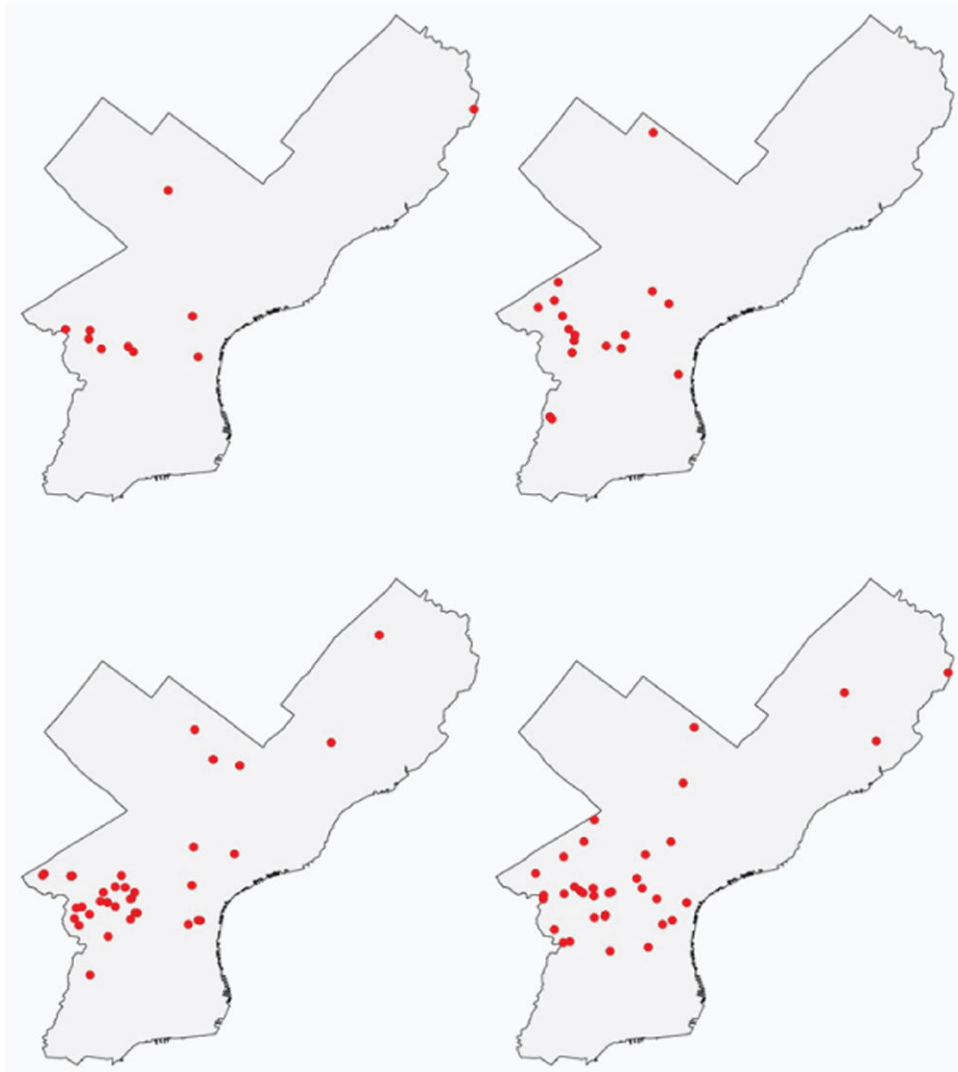


Figure 7.

Maps of risky places for substance users by age subgroups (top left: age 13-14; top right: age 15-16; bottom left: age 17-18; bottom right: age 19-20). Different age subgroups have different numbers of substance users and magnitude of spatial dispersion of risky places.

Table 1

Variables displayed by the QAV.

Variable Type	Variable Name	Description	Value Domain
Subject-Based	Substance Use	Whether the subject is a substance user	User Non-User
	Gender	Male or female	Male Female
	Age	Age in years	Continuous
Activity Space Location-Based	Perception	Subject's perception of the location	Home, Safe, Risky, Important, Favorite, and Religious
	Time of Day	Typical time of day to visit the location	Daytime (before 6pm) Nighttime (after 6pm)
	Day of Week	Typical day of the week to visit the location	Weekend (M-F) Weekday (Sa/Su)
	Length of Stay	Typical length of stay at the location	Less than a half hour Half hour to an hour One to two hours More than two hours
	Type	The type of place: e.g. school, restaurant, street corner, recreation center, etc.	Text
	Description	Qualitative explanation of the adolescents' selection of locations and feeling at the location	Text
	Social Network Quality	An index of the degree of risk or protection of an adolescent's social network at each location, where a positive score means protective influence and a negative score means risky influence	Continuous (ranging from -70 to 70)
	Geographic Variables	29 geographic variables reflecting community resources and socioeconomic character at each type of activity space location (see Table 2 for complete list)	Continuous
Path-Based	Transportation	Mode of transportation taken to visit the location	Motor vehicle Walk/bike
	Distance	Shortest path distance along street network from home to location in feet	Continuous

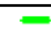
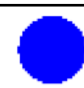
Table 2

Geographic Variables.

Distance to Nearest Recreation Center (meters)
Distance to Nearest Head Start (meters)
Distance to Nearest Head Start Partner (meters)
Distance to Nearest Place of Worship (meters)
Distance to the Nearest Park (meters)
Distance to the Nearest Alcoholics Anonymous Meeting (meters)
Distance to the Nearest Narcotics Anonymous Meeting (meters)
Distance to the Nearest Bar or Restaurant Serving Alcohol (meters)
Distance to the Nearest Store Selling Packaged Beer (meters)
Distance to the Nearest Pawn Shop (meters)
Distance to the Nearest Check Cashing Store (meters)
Distance to the Nearest Police Station (meters)
Density of Weapons Offense Arrests within 1 km (arrests/km^2)
Density of Violent Offense Arrests (arrests/km^2)
Density of Drug Sale Offense Arrests (arrests/km^2)
Density of Drug Possession Offense Arrests (arrests/km^2)
Percent African American
Percent Female Headed Households with Children
Percent Spanish Speaking
Percent Foreign Born
Percent Completed High School
Percent Unemployed
Median Housing Value (U.S. dollars)
Median Household Income Value (U.S. dollars)
Percent Receiving Public Assistance Income
Percent Living Below the Poverty Line
Percent of Housing Units Vacant
Median Year Housing Structure Built
Population Density (people/km^2)

Table 3

Graphic symbology of variables used in the QAV.

Attribute Variable	Visual Variable	Values	Visual symbols
Mode of Transportation	Color of path line symbol	Walk/bike	
		Motor vehicle	
		Unknown	
Perception	Color of circular point activity space location symbol	Home	
		Safe	
		Risky	
		Favorite	
		Religious	
		Important	
Time of day	Symbol attached upper left to location symbol	Daytime	
		Nighttime	
		Multiple response	
Day of week	Symbol attached upper left to location symbol	Weekday	
		Weekend/holiday	
		Multiple response	
Length of stay	Size of location symbol	< 30 min	15
		31min - 1hr	25
		1 - 2hrs	35
		> 2hrs	45

Attribute Variable	Visual Variable	Values	Visual symbols
Geographic variables	Size of proportional bar symbol attached left to location symbol	Continuous	