# BATS: The Blind Audio Tactile Mapping System

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## ABSTRACT
The BATS project focuses on helping students with visual impairments access and explore spatial information using standard computer hardware and open source software. Our work is largely based on prior techniques used in presenting maps to the blind such as text-to-speech synthesis, auditory icons, and tactile feedback. We add spatial sound to position auditory icons and speech callouts in three dimensions, and use consumer-grade haptic feedback devices to provide additional map information through tactile vibrations and textures. Two prototypes have been developed for use in educational settings and have undergone minimal assessment. A system for public release and plans for more rigorous evaluation are in development.

## Categories and Subject Descriptors
K.4.2 [**Computers and Society**]: Social Issues – a*ssistive technologies for persons with disabilities.*

## General Terms
Human Factors

## Keywords
education, spatial sound, tactile feedback, maps, visual impairment

## 1. INTRODUCTION
Spatial information is often presented in the form of maps that viewers actively explore to learn about an area. People who cannot see cannot share the benefits of such a visual representation, and have traditionally relied on audio descriptions, tactile maps, guidance from others, and even trial and error when learning the layout of a region. On-going assistive technology research has yielded a number of promising techniques to help people who have visual impairments plan daily walks and get directions, but little has been done to promote the same kind of spatial awareness provided by visual maps. The BATS project focuses on the latter area of research by helping people without sight access and explore spatial information.

Assisting students with visual impairments in reading maps is our avenue of choice for improving access to spatial information. Starting early in education, emphasis is placed on developing the spatial reasoning skills of young students. Concepts like north, south, east, and west are of importance in these students' studies in order to build their awareness of the world around them. As students mature, more complex spatial relationships are introduced, especially in geography. Maps are used to reinforce previously learned concepts like compass direction while introducing new notions of coordinate systems, relative distance, boundaries, perimeter, and area.

Alternatives to printed visual maps are few to none in typical classrooms. While pupils with sight learn about local and foreign lands from detailed visual maps, mainstreamed students with visual impairments either work with makeshift maps built by their teachers or just sit patiently doing nothing because of a lack of appropriate materials. This imbalance in classroom learning between sighted and unsighted scholars is simply unacceptable considering the capabilities of computers to present information in forms other than images.

In this paper, we first report on previously developed techniques for aiding the blind in navigation and general map reading. Next, we discuss our approach to conveying map information to students using spatial sound and touch. Finally, ideas for future BATS research and development are presented.

## 2. RELATED WORK
Nearly all research related to assistive mapping can be classified in two categories. The first body of work focuses primarily on providing orientation and navigation assistance to users with visual impairments. Aids that fall into this category include white canes and guide dogs as well as more advanced handheld [1,2,3], wearable [4,5], and fixed position [6,7] devices. The second collection of research concentrates mainly on helping people build an understanding and awareness of spatial information. Tools that match this description include low-tech paper tactile maps as well as digital map exploration software [8,9].

Our vision of BATS fits into the second line of research. However, findings and techniques from orientation and navigation research should not be neglected. Assisting users in exploring maps is a task akin to helping users navigate in the real world. In fact, our ultimate goal is to make map exploration as familiar and natural as actually walking through the regions portrayed on a traditional paper map. Consequently, we have investigated developments in both bodies of work.

## 2.1 Aids for Navigation

A number of electronic devices have been developed to help users without sight navigate in the real world. Some of the earliest handheld electronic devices, including the Mowat Sensor [1] and the Sonicguide [2], used tactile vibrations and audio feedback to alert pedestrians to obstacles. Wide-spread acceptance of these devices was stunted, however, because the burden of sweeping the sensor around an environment was placed on the user.

More recent devices have improved the assistance afforded to pedestrians with visual impairments. The GuideCane [3] relieves the burden of pointing a sensor to detect obstacles by placing the electronics in a wheeled cane. This device is capable of directing pedestrians around obstacles by pulling them in the correct direction as they walk. The device developed in [4] places the necessary sensing and guidance electronics on the user in a wearable interface. Orientation information is returned to the user in the form of a directional bell sound, spoken headings, and taps on the back. Another wearable device, Drishti [5], relies entirely on speech input and text-to-speech output for communicating walking routes and travel conditions.

Other navigation research seeks to aid travelers with visual impairments without requiring them to carry or wear cumbersome electronics. The simplest approach, taken by the commercial product Atlas [6], allows users to plan routes on a personal computer before traveling. Another method adopted by Talking Signs® [7], places electronic identifiers and navigation aids along routes of travel. With this system, pedestrians who cannot see need only carry a simple infrared receiver to identify landmarks, determine the state of traffic lights, and line-up with crosswalks.

## 2.2 Aids for Learning

Systems more closely related to BATS encourage the exploration of maps. The work by the Haptic Soundscapes team [8] defines many of the techniques for non-visual map reading used in BATS, including text-to-speech synthesis and auditory icons. In their system, users are encouraged to traverse a map using a touchpad in an attempt to build a mental model of the map's geography. The constructive exploration system [9] also promotes the study of map content, and features the use of the Phantom force feedback device for feeling map features.

Like the two systems mentioned above, we focus on creating a constructivist learning experience in BATS that emphasizes the active participation of users in map exploration. Unlike previous efforts, however, we direct our attention specifically at the needs of students with visual impairments and their study of maps.

# 3. TECHNIQUES

We have combined standard text-to-speech, auditory icon [10], and tactile feedback methods for conveying map information to the blind with two techniques most commonly associated with video games by students and children. The first, spatial sound, is often used to create a realistic audio ambience in three-dimensional video games. The second, haptic feedback, is employed to provide physical stimuli from virtual actions and reactions in games. Not only are both of these techniques capable of providing map content cues to users, but they are also very familiar to video game playing children.

## 3.1 Spatial Sound

Spatial sound refers to audio played from headphones or speakers that appears to originate from a point in three-dimensional space. Audio is filtered before playback in a manner such that the resulting sound waves reach a listener's ears in much the same way as if the sound had originated from a point in true three-dimensional space [11]. Spatial sounds may play from all directions and distances in the virtual world, and are only limited by hardware. The realism of the effect is improved, of course, by using more sophisticated audio equipment like, for example, a surround sound system. Nevertheless, we have achieved a convincing separation of left from right, and a minor separation of front from back using standard headphones, inexpensive sound cards, and readily available spatial sound libraries.

### *3.1.1 Spatial Auditory Icons*

We have combined spatial sound with auditory icons to play environmental sounds from appropriate distances and directions. This approach allows a region of interest on a map to identify itself by its sound, indicate its direction relative to the user's current center of attention by the direction of its sound, and signal its distance from the user's focus by the volume of its sound. For instance, a city far to the east of a user's current cursor position sounds like a faint, yet steady stream of traffic coming from the right.

In effect, this technique creates a virtual environment in which sounds fade into and out of a user's range of hearing as he or she explores a BATS map. This approach closely mimics the way in which people with visual impairments use sound to orient and navigate in real life. In fact, spatial auditory icons have been used to develop the spatial awareness skills of youths with impaired vision [12].

### *3.1.2 Callouts*

We have also combined spatial sound with speech to create a callout effect. Spatial auditory icons only manage to identify the types of nearby regions. Cities emit traffic sounds and forests play sounds of bird chirping, but neither identifies which city or forest is nearby. Spatial speech allows these same regions to announce their names from their map locations on demand. For example, three cities all play similar spatial traffic sounds when a user is exploring nearby. When a user requests a callout, each of the three cities announces its name in turn as Raleigh, Durham, and Chapel Hill from its respective spatial location.

Adding callouts to an environment of spatial auditory icons allows a user to be more selective in his or her exploration. Combining these approaches helps a user locate points of interest on a map based on their iconic sounds and identify which warrant further investigation based on their spoken names. In addition, callouts provide some indication of spatial relationships among nearby points.

## 3.2 Consumer-Grade Tactile Devices

In addition to sound, we use consumer-grade mice, trackballs, joysticks, and gamepads capable of providing force feedback to the hands of a user. Typically, these devices have the ability to play a number of effects including vibrations and textures. The most advanced of these gadgets are able to apply directional forces strong enough to move the hand of a user. We are interested in using these effects in BATS in order to alert users to regions of interest during map exploration.

As mentioned previously, haptic devices have been used to convey information in map systems in the past. In most cases, however, the devices used have been of professional quality and well out of the price range of common users. In BATS, we seek to make use of commercial tactile devices that are available for purchase by users at a cost typical of standard computer input devices. For example, the Kensington Orbit3D tactile trackball and Logitech Wingman rumble gamepad we have used with BATS cost approximately $35 each. Since our focus is on developing BATS for use in education, affordability of hardware is of importance in our work.

Familiarity with the tactile devices supported by BATS is also of value to us. Most adult computer users, including those that have a visual impairment, have encountered and worked with mice and trackballs as input devices. Similarly, most children, also including those that have a visual impairment, have interacted with video game controllers and joysticks. As such, we intend to focus predominantly on using and evaluating these four classes of input devices with tactile feedback.

**Figure 1. Logitech Wingman gamepad and Microsoft Sidewinder joystick**

# 4. BATS: ROMAN BRITAIN

## 4.1 Motivation

The first BATS prototype was developed by a team of undergraduate students in a software engineering class at UNC. Over the course of the spring 2002 semester, this team of five students worked with Jason Morris, a graduate student born with a visual impairment, to develop a system capable of improving his studies of Great Britain during Roman occupation. A collaborative effort was maintained throughout the semester in order to build a system that fit Jason's specific needs and to learn from Jason's feedback. Connections were also made with the Ancient World Mapping Center at UNC to help the team learn more about geospatial information systems (GIS) and mapping.

Before the start of the project, Jason investigated the use of crude tactile maps for his research. Such maps are created by printing raised outlines, markings, and Braille on thick paper. The maps are then used by feeling for features such as land-water boundaries, elevations, reference points, and text. For instance, one tactile map of the British Isles he encountered has raised markings for the borders of the islands, references for information in a Braille key, and regular Braille text for names of major regions such as the Atlantic Ocean.

The use of these printed tactile maps is of limited value, especially in graduate level research, for a number of reasons. First, the amount of information that can be presented on a tactile map is limited by its physical dimensions. Raised features like Braille can be packed only so densely before they begin to run together and lose all meaning. Second, the shapes of coastlines and political boundaries are not accurately represented on tactile maps. These complex, high-frequency features are purposely misrepresented to provide an estimate instead of an exact understanding of their shape. Third, the use of a separate key for more information is tedious and interrupts the exploration process. Finding a reference mark, reading the mark, shifting attention to the key, finding the reference index on the key, reading the key information, and then shifting attention back to the same location on the map is a difficult and time consuming task.

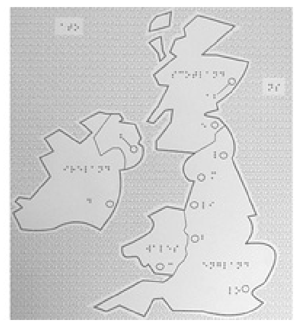

**Figure 2. Paper tactile map of Great Britain**

These limitations led the BATS team to develop a software system for exploring a digital map of Roman Britain. The software system provides a marked improvement over similar tactile maps for its ability both to convey information in a non-visual form and to present a virtually unlimited amount of information.

## 4.2 Design

### *4.2.1 User interface*

The user interface of this prototype employs a pointing device and keyboard for input, and relies on aural output. A user explores the map of Roman Britain by moving the on-screen cursor with a standard input device such as a mouse, trackball, or touch-screen. Once positioned, the user clicks a mouse button or presses a key on the keyboard to query for information about the point directly under the cursor and the surrounding area. A map image is also shown on-screen for sighted users.

Answers to queries are returned using both auditory icons and text-to-speech synthesis. For instance, moving the mouse over the ocean causes the sound of crashing waves to be played, while clicking the mouse button over a city causes it to announce its name. Information about regions surrounding the current cursor position is also presented using auditory icons, but this time using spatial positioning. For instance, querying regions to the west of the current cursor position causes them to play their audio icons or announce their names solely in the left speaker or headphone. If a river and city are found to the west, the user will hear water bubbling from the river and the name of the city announced to the left side of his or her head.

The combined application of both auditory icons and speech helps to create a complete audio user interface. Using audible icons for initial feedback provides identifying information about a point or area without interrupting or requiring the full attention of the user. Speaking information for additional feedback provides more details about a particular point of interest in a more information-rich format. Applying spatial sound playback to both aural icons and speech when appropriate adds an extra cue as to location of regions of interest relative to the user's current position.

#### *4.2.2 Queries*

BATS: Roman Britain supports a plethora of queries designed to assist Jason in his research. Simple information, such as settlement names, types, and establishment dates, can be spoken by the system when a given point is queried. More detailed information like the spelling of Latin region names and the elevation of any point can also be spoken on demand. Markers for measuring distances between points of interest can be set, and the measurement values can be read aloud. Searches for points of interest can also be performed in order to quickly position the cursor at a desired location.

Area queries can be executed by a user as well. As mentioned earlier, information about nearby regions is rendered using spatial sound and presented to the user both as audio icons and speech. A user simply chooses a cardinal compass direction (i.e. N, NE, E, SE, S, et al.) around their current cursor position to hear auditory icons of rivers, lakes, and oceans, and spoken names of settlements played in the chosen direction.

### 4.3 Implementation

The BATS: Roman Britain prototype is coded in the Python programming language to support rapid development. The wxPython library is utilized to provide user event handling and a limited graphical user interface—namely, a static map image of Roman Britain. The Microsoft Speech API (MSAPI) is used to provide speech capabilities, while the Open Audio Library (OpenAL) is employed to play audio icon sound files directly or positioned in space. Data for the map is accessed through an Open Database Connectivity (ODBC) driver attached to an Access database file. The software is written specifically to run on the Windows operating system.

The map image and data attributes are exports from a GIS dataset. ArcGIS is used to prepare the GIS data for use in BATS by creating the image for display and by exporting map attributes to the Access database.

Readers interested in the BATS: Roman Britain software are encouraged to download the source code from our SourceForge repository. It can be accessed via our homepage at http://www.cs.unc.edu/Research/assist/bats.

### 4.4 Evaluation

This first BATS prototype has not been evaluated in a formal user study. Nevertheless, Jason's use of BATS in his studies of Roman Britain has been observed to give us some insight into the strengths and weaknesses of the system.

Originally, the team had agreed that the use of a touch-screen would promote the understanding of spatial relationships better than standard mouse, trackball, and keyboard input devices. We believed the proprioceptive sense would allow Jason to more intimately explore BATS maps and gain an awareness of their content. Surprisingly, after one use of the touch-screen, Jason pointed out that he preferred a trackball for map exploration simply because he grew tired from moving his arms to and holding his arms at positions on the touch screen. We had not thought of this problem previously, and have taken note of it for future BATS designs.

The keyboard commands in BATS: Roman Britain seemed to be difficult to master by Jason and even the rest of the team. Assigning all of the query commands to the numeric keypad appeared to be convenient for quick user access and appropriate for directional queries. However, having two modes in order to reuse the same set of keys for all the commands proved confusing at times. Balancing rapid command access using hotkeys like those in the Roman Britain system with a more verbose speech system is a possibility for future designs.

**Figure 3. Jason, Tom, and Thomas discussing the Roman Britain system**

The most interesting result we noted from Jason's use of BATS, however, was his ability to draw conclusions from the presented data. After learning how to use the system and exploring the map of Roman Britain for a few days, Jason was able to write a research paper for one of his classes correlating settlement distances and the hierarchy of regional governments during the time period. Clearly, Jason gained some awareness of the spatial relationships of villages across Roman Britain from his use of BATS, regardless of the limitations of the user interface.

## 5. BATS: NORTH CAROLINA

### 5.1 Motivation

A second BATS prototype was developed by our research group during the fall of 2002. Our efforts during this time period focused on four major areas of interest. First, we wished to create a BATS system accessible by younger students. The map of Roman Britain was designed specifically for Jason's studies, and featured a complicated user interface. For this prototype, we wished to create a more familiar map and simplistic user interface to evaluate our techniques across a more diverse student population.

Second, we wanted to improve our use of spatial sound to provide cues for direction and distance. In the Roman Britain system, spatial sound is used when a directional query is performed by a user, in which case sound is only played in the direction of the query. The benefits of using spatial sound in such a manner seem limited because the user must continually query as he or she explores to avoid missing regions of interest. Creating a more free-form environment of sound in which audible icons fade into and out of hearing distance seems more natural and of greater assistance in effortlessly locating map features using audio.

Third, we hoped to explore the ability of inexpensive tactile feedback devices to convey map information. Speech and sound are used exclusively to indicate when a user has the cursor positioned over a settlement or water respectively in the map of Roman Britain. These techniques are fitting for telling a user when they directly over a region of interest, but are poor at designating changes and boundaries on a map. Simple tactile effects like bumps and textures available on haptic devices seem to be more effective at signifying when a user has crossed a political or geographic boundary.

Finally, we wished to gain a better understanding of GIS data and its formats. In the Roman Britain prototype, we relied heavily on ArcGIS for exporting a visual map and its associated data attributes in a raster format. We quickly realized, however, that in order for BATS to find mainstream use, it would need to more readily support maps rendered directly from GIS data sources. Our BATS North Carolina map still relies on the use of ArcGIS to export a map image and its associated attributes, but its creation afforded us the opportunity to explore the structure of GIS data more deeply in order to bring about improvements in future systems.

## 5.2 Design

### *5.2.1 User interface*

The user interface for the North Carolina map uses a pointing device for input, and employs aural and tactile techniques for output. A user explores the map by moving a cursor with a mouse, trackball, joystick, or gamepad with at least two buttons. As the cursor moves across the map, the input device provides a slight bump at county boundaries, a large bump at state boundaries, and a constant vibration on cities. At the same time, spatial auditory icons are played to indicate regions near the cursor. The position and volume of the sound icons are updated each time the cursor moves. A visual map image is also provided for the sighted.

The first button on the input device is used to query any point on the map for spoken information. Repeated presses of the button cause more facts to be read aloud. For instance, clicking on a county three times in a row announces its name, population, and area. In another example, clicking on a state three times announces its name, area, and perimeter. Once the last piece of information has been spoken, the cycle starts over.

The second button on the input device is used to start a callout of city names. Once pressed, nearby cities announce their names in a counterclockwise order starting in the east. The callouts are rendered using spatial sound, as described previously, to provide an indication of the distance and direction of the cities from the current cursor position.

The gamepad and joystick we tested with the North Carolina map feature additional buttons beyond the main two. These buttons are mapped to additional functions like cycling backward through the list of spoken information for each point of interest and stopping all speech immediately. These devices also feature a slide throttle that controls the speed of cursor movement during map exploration.

### *5.2.2 Queries*

The North Carolina BATS map makes use of a much simpler set of queries than the Roman Britain map. Reducing the number of queries simplifies the user interface and helps target the system at younger children.

In total, the system supports three kinds of inquiries. Passive area queries occur whenever a user moves the cursor. This kind of query triggers tactile effects and starts, stops, or updates spatial auditory icons. Active area queries happen whenever the user presses the second button on the input device. Callouts from cities surrounding the cursor result from this query. Point queries occur whenever the main button is pressed. Spoken information about the point under the cursor is returned when such a query is performed.

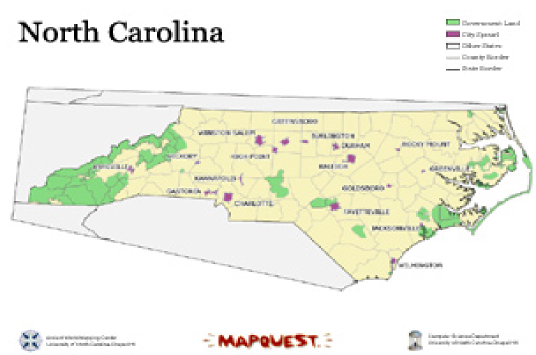


**Figure 4. BATS map image of North Carolina**

## 5.3 Implementation

The BATS: North Carolina prototype is also coded in the Python programming language and uses the same libraries as the Roman Britain system. In addition, the Immersion Foundation Classes (IFC) are used to provide tactile effects.

The data and image of North Carolina are taken from a GIS dataset provided by MapQuest. The map attributes are exported as an Access database, and the map image is exported as a standard bitmap. A second index bitmap is also exported that allows map areas to be matched with their associated attributes in the database via a numeric key encoded in the colors of the index image. Once again, ArcGIS is used to generate the exports.

Readers interested in the BATS: North Carolina software are encouraged to download the source code or executable from our webpage at http://www.cs.unc.edu/Research/assist/bats.

## 5.4 Evaluation

Our BATS North Carolina map has only recently been completed and has not been evaluated in a suitable classroom setting. We have only observed a number of users, sighted and blind, informally interacting with the system.

We were given the chance to observe four high school students, three fully blind and one partially blind, working with an early version of the North Carolina BATS software. At the time, the software featured a rudimentary visual map of North Carolina and its neighbor states, spoken information about states and cities, tactile feedback for major geographical regions, and callouts from cities. To our surprise, even at this early stage in development, the students quickly learned the controls of the system and successfully navigated toward cities by repeatedly using the callout feature.

**Figure 5. A student from Athens High School using BATS: North Carolina**

## 6. FUTURE WORK

We will continue our development of BATS with feedback from BATS users and support from content providers. We are currently talking with teachers, mobility specialists, and students in local K-12 classrooms to secure an educational environment for the use and evaluation of BATS. We are also speaking with MapQuest about the creation of BATS compatible maps for all fifty U.S. states. Our collaboration with these two parties should help us craft BATS to meet the needs of its users and the requirements of mapping community.

Taking what we have learned from our first two prototypes, we have started the development of a more robust version of BATS for public release. We have planned a number of improvements to the techniques used in our maps of Roman Britain and North Carolina including the following:

- A map maker utility capable of creating BATS maps from common GIS file formats without reliance on ArcGIS
- An improved system of callouts that speaks the names of the nearest point of interest in each compass direction regardless of its distance from the current cursor position.
- A method for recursively zooming [13] into regions of interest on a map in order to display more details about that region
- An interface that supports the simultaneous use of both touchpads and tactile feedback devices for coarse and fine exploration respectively

Finally, we plan to always keep our work under an open source license. We strongly believe our computer science research should be performed as a public service. As such, our software will be made available without restrictions during all phases of development.

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