Geospatial Accessibility and Inclusion by Combining Contextual Filters, the Metaverse and Ambient Intelligence

Yaron Kanza
AT&T Chief Data Office
kanza@research.att.com

Balachander Krishnamurthy
AT&T Chief Data Office
bala@research.att.com

Divesh Srivastava
AT&T Chief Data Office
divesh@research.att.com

ABSTRACT

Accessibility and *inclusion* in information systems provide guidelines and methods for building applications and devices that work for everyone, including for people with disabilities and other diverse characteristics. Systems that apply accessible and inclusive design (AID) provide an easy way to adapt features for people with different capabilities. In geospatial applications and wearable technology, aspects of location and time should be taken into account as well. In this paper we present a visionary approach of applying *contextual filters* to the input, output and the underlying dataset of geospatial applications, to examine adaptation of systems, devices and applications to different populations and for verification of accessibility and inclusion. The goal of AID is to help developers add accessibility features to their systems and provide transparency regarding lack of accessibility when needed, e.g., make it clear if there are features that prevent usage by people who lack certain abilities. We explain how to apply AID in physical and virtual worlds, like the *metaverse*, and we describe how ambient intelligence, accessibility maps and virtual worlds can assist in building accessible and inclusive geospatial applications. We present our vision and elaborate on related challenges and research directions.

CCS CONCEPTS

•Social and professional topics →People with disabilities;
•Information systems →Spatial-temporal systems;

KEYWORDS

Accessibility, inclusion, disability, wearables, ambient computing

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1 INTRODUCTION

Addressing disabilities and limitations of diverse populations when developing applications is receiving growing awareness recently [1, 14], e.g., W3C has published[1] recommendations for accessibility, utility and inclusion in web pages. The main goal of *accessibility* and *inclusion* is creating applications that work for everyone. Accessibility addresses discriminatory aspects by providing a similar user experience or a similar service to different people, including to people with disabilities. Inclusion requires coping with diversity, and ensuring that everyone can use the application, to the greatest extent possible. Products should be designed for all, while taking into account differences in physical and mental abilities, technological skills and literacy, age, and cultural diversity. Spatio-temporal effects should be considered when applying these principles to geospatial applications, mobile devices and wearable technology.

Some aspect of accessibility are covered by law, e.g., by the Americans with Disabilities Act of 1990 (ADA, https://www.ada.gov/), which prohibits discrimination against people with disability. It took decades to establish accessibility regulations and guidance rules for physical facilities and the web (see https://accessibility.day/). However, the advent of new geospatial technologies like the metaverse and wearable technology creates new challenges and provides opportunities for building better tools for developers to comply with the law. Thus, accessible and inclusive design (AID) has the following goals. First, guaranteeing that applications and devices work for all users. Second, preventing the effect of biased data on accessibility and inclusion. Third, protecting users from harmful intrusive devices and applications that limit accessibility of other users. The following examples illustrate these cases.

Consider a navigation app that computes a route from the user location to a specified destination and then provides turn-by-turn instructions along the way. Using an improper color palette might prevent users with color blindness from seeing some of the information, e.g., they may not be able to distinguish between green and red routes. The voice command feature might not recognize all accents. Sounds and voice commands might not be clear enough for people with hearing impairment. A recommended route by public transportation or by foot should guarantee accessibility for people in a wheelchair or with a stroller. For people who have sun allergy (photosensitivity) or light sensitivity (photophobia), the app should heed exposure to sunlight by taking daylight time into account.

Accessibility can be affected by geospatial bias, e.g., this has been observed in Pokémon GO [8]. Pokémon GO is a location-based augmented-reality game in which players discover hidden creatures using their smartphone. Colley et al. [3] revealed geographically-linked biases and safety risks in the game. They showed that the design of Pokémon GO heavily advantages urban places with few minorities. This leads to lack of inclusion, where the user experience of players in poor neighborhoods, suburban areas and rural areas is not on a par with that in rich neighborhoods.

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[1] https://www.w3.org/WAI/fundamentals/accessibility-usability-inclusion/

Lack of accessibility and inclusion can affect not just systems and mobile apps, but also wearable devices [16]. Wearable devices are gaining popularity in recent years, including fitness trackers, smartwatches, VR headsets, smart clothing, smart eye-ware, sleep trackers, posture trackers, etc. For accessibility and inclusion, these devices should provide the same user experience to all users, as much as possible [14, 19]. For instance, does a smart eye-ware device provide the same user experience to all users, including nearsighted people and farsighted people? Is the same experience provided at daytime and nighttime? How do rain, snow or strong sunlight glare affect the user experience? All these should be tested not just for different users, but also for different locations and times.

An important aspect of AID is to guarantee that systems and devices are not being exploited by the user for harming others or limiting accessibility and inclusion of other users. For example, AirTags and the "Find Me" app were designed for tracking items, but have been used for secretly tracking people without their knowledge or consent [13]. AirTags can be used for collecting location information that would harm people or be used for discriminating against certain populations, e.g., secretly tracking people could be used for finding places that were visited by them and infer their religion, sexual orientation, political affiliation, drinking habits, etc.

In all these examples, tools and guidelines should lead to designing apps in a socially responsible manner that takes accessibility and inclusion into account, for different locations and times. This is a complex task due to the large diversity among people and geospatial applications. Our goal is to examine geospatial applications in physical and virtual environments, e.g., by using ambient computing and applying contextual filters to geospatial applications, to test and design applications for a variety of disabilities, locations, times and contexts. Another goal is to embed the notion of accessibility in new areas of technology like the metaverse. We want to avoid replicating existing accessibility issues in these new technologies.

The vision: *Build geospatial applications for all by testing applications in virtual and physical worlds using contextual filters and by adapting geospatial application to people with disabilities using ambient intelligence.*

In this paper we present the novel approach of testing and supporting AID in geospatial applications by using contextual filters, ambient intelligence and the metaverse.

2 CONTEXTUAL FILTERS

To examine accessibility and inclusion, different types of disabilities and limitations should be considered. This includes, for instance, vision impairment, hearing impairment, physical disability, orthopedic impairment, speech disability or foreign accent, cultural and religious limitations, mental health conditions like social anxiety disorder, autism, etc. It also includes being accompanied by young children, pets or people with mental disorder. All these conditions could restrict users when traveling, going to a restaurant, seeking an apartment for rent, and in many other activities. Geospatial search tools and location-based recommendation systems should be adapted to such restrictions. But coping with a large variety of cases requires understanding the limitations of each group and applying suitable adaptation based on the user needs.

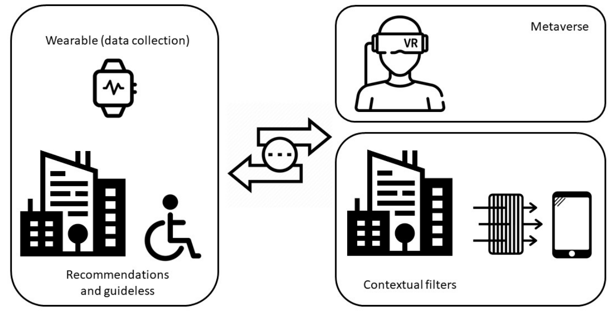

Figure 1: A circular process of collecting data, testing accesibility using contextual filters and the metaverse, applying adaptations, and starting the process from the beginning.

We suggest the use of *contextual filters* as a way to examine accessibility and inclusion in geospatial applications and guide AID. Contextual filters may not cover all disabilities, but they could assist in many common cases. Contextual filters can be applied to the input, output and underlying datasets of applications. They mask part of the input, output and data to create limitations similar to disabilities. For geospatial applications, masking may depend on the location and the time. For example, masking the output voice instructions and sounds will help examine accessibility for users with hearing impairment. Distortion of the input voice recognition will help examine inclusion of people with different accents. Removing from the dataset businesses, road segments and means of transportation that are not suitable for people in a wheelchair will examine the usefulness of applications for people in a wheelchair.

An input, output or data filter is a function f_i, f_o or f_d that masks part of the input, the output or the underlying dataset, respectively, based on contextual conditions. These functions imitate limited abilities of users. Different programming paradigms facilitate the implementation of such filters. *Aspect-oriented programming* [7] adds behavior instructions to code without modifying the code itself, and *composition filters* [2] provide a mechanism for adding filters on incoming and outgoing messages, to control the behavior of objects in the code. These paradigms can be administered in mobile apps [15]. By using context-aware aspects [18] and changing the behavior of the application based on context [9, 11], the filters can be applied according to location, times and nearby users.

The following are three usages of filters in AID. First, verifying inclusion by testing that the app is suitable for different types of users. Second, modifying the behavior of an app, to accommodate it to people with special abilities. Third, including in apps features that help users with access to places, utilities and other apps.

Testing Accessibility and Inclusion. When testing accessibility with filters, restrictions are made by applying f_i, f_o or f_d, to examine to what extent a user with a disability, or with any other limitation, could use the application. For example, is a smart watch useful for people that have a limited range of motion in one of their arms. This should be tested while taking the context into account. The watch might include a Voice Command feature, which may work in some places but might be limited in very loud locations. In some situations, nearby people might help to activate the touchscreen, but when driving or exercising, help from others might be limited. A contextual filter could help to test the limitations of the device by disabling the functionality according to the context, and examine edge cases, e.g., disabling the touchscreen when driving or exercising. This would give testers and developers the ability to experience the use of the device by people with a disability.

Accommodation. Testing applications and devices can help to discover accessibility issues in applications and find features that do not work well for all users. The goal of AID is to fix such limitations, when possible. For example, fitness trackers often measure progress in steps, and that makes them unsuitable for people in a wheelchair [6]. An adapted measure will increase inclusiveness.

Developers can add supporting accessibility features. For people in a wheelchair (or with a stroller), recommendation systems should propose locations and routes that are suitable for a wheelchair. For people with a vision impairment, sounds and voice commands might be designed to replace the visual display (this is also useful against sun glare). For people with hearing impairment, visual display, vibrations and captions might replace sounds and voices. Note, however, that AID is not just personalization, it is a suite of tools to test and support accessibility and inclusion.

Effective accommodations should be contextual and take location and time into account. For example, sounds may not work in a noisy subway, visual display may not work while driving, and sidewalks may be inaccessible when covered by ice or snow. Thus, contextual accommodation should be tested for a variety of contexts.

Adding Accessibility Features. Devices and applications that are designed for people with disability could increase the accessibility of apps, services and facilities. This requires awareness by developers, e.g., by letting them experience the world the way people with a disability perceive it. Contextual filters can do this as augmented reality (AR) features. For instance, presenting on a smartphone the world the way a person with vision impairment sees it will let testers and developers learn about the needs of people with vision impairment, e.g., sensing how they cope with stoplights or street signs. An AR app could show places that are inaccessible to people in a wheelchair or with a baby stroller. This could guide developers to adapt recommendation systems to limitations of people.

It is also useful to test the effect of assistive features like captions, ML-based translation of sign language, text to speech, speech to text, and image to text, to examine when and where they help users.

3 ACCESSIBILITY AND THE METAVERSE

There are cases that require testing accessibility through interactions with people, in a variety of contexts. This could be done in the *metaverse*. The metaverse is an immersive virtual world that provides an enhanced sense of presence within digital spaces, while users can remotely interact with one another through virtual reality and augmented reality devices [4]. The metaverse could also serve as an accessibility tool, e.g., to support tele-medicine, especially during a pandemic, and facilitate access to healthcare. But this requires that the metaverse itself will be accessible.

To use the metaverse for effective testing of accessibility and inclusion, real-world environments should be modeled as accurately as possible. Contextual filters could be added to avatars to limit users and let them experience disability. Filters could affect what users see or hear in the metaverse, could limit mobility of users in the virtual world and could make interactions with other users harder than without filters. This will allow users experience disabilities, of different types. It could help application developers to examine the effect of disabilities on interactions with people.

The use of virtual worlds could facilitate simulations of different contexts, like different locations, times, weather conditions and presence of other people. Game developers could simulate the experience of location-based games, like Pokémon GO, in different locations, to see if there is the same user experience in all places. It will be challenging but useful to test in virtual environments tracking devices and their effect on privacy, prior to releasing such products to the market. Virtually examining in the metaverse wearable devices, like AirTags and smart glasses, could give developers the ability to test the reaction of users to these technologies.

To test accessibility in the metaverse, the list of filter should be extended to capture dexterity and sensory limitation and make sure that applications are adapted to people who have physical limitations or suffer from nausea.

4 AMBIENT INTELLIGENCE

Ambient Intelligence can be used to test accessibility in the real world. It focuses on creating technology in which people seamlessly use computers and artificial-intelligence applications [5, 17]. It combines artificial intelligence with ubiquitous computing (pervasive computing), context awareness and personalization, to smoothly adapt the behavior of applications to the user needs, without letting the user being aware of that. Thus, ambient intelligence and wearable devices can support geospatial accessibility and inclusion by (1) collecting relevant data, (2) providing accessibility tools, and (3) facilitating communication regarding disability.

Data collection. Wearable devices can collect essential data for AID, e.g., for machine learning (ML) applications [10]. Collected data could vary. For instance, accurate location data of people in a wheelchair can be used for creating ML models that distinguish between accessible and inaccessible locations. Recorded sounds can be used for learning where and when people with hearing impairment might need help, and so on.

Collected data could be used for training ML models, to predict accessible locations based on the context, and for detecting accessibility flaws in ML models. For example, access to places or systems is often based on biometric data like face recognition. But the technology is sometimes biased [12], leading to false positive and false negative cases, due to recognition failure. Access data could help planners detect failures and improve the authorization system. Ambient intelligence could make data collection seamless and ML-guided, to collect data just when needed.

Accessibility tools. Ambient intelligence could be utilized for adapting devices and applications to different people. For example, sounds and voice instructions could be automatically replaced by vibrations and captions, for people with hearing impairment. The captions could be in various languages, to increase inclusion. Devices could also adapt their color scheme and brightness based on user requirements and the time of the day. The goal is to provide features and functionality that help coping with disabilities.

With ambient intelligence, devices could alert users, if needed, e.g., issue a hazard when there is ice on the sidewalks. The device could also recommend an alternative venue or route, based on the conditions in the area and the limitations of the user.

Facilitating communication. Often, devices could connect with other nearby devices to communicate issues related to a disability. Ambient intelligence could be used to indicate on devices of other users that a person needs help or special attention. For example, a smartphone app might guide elderly people to an empty seat on the subway or may send a message to nearby people asking if they can help by giving their seat to the person who needs it. Moreover, smartphone apps or wearable devices could interact with doors, doorbells, streetlights, escalators, etc. Automatically transmitting the limitations of the person could be translated into a supporting action like opening the door, ringing the doorbell, dimming the streetlight, slowing down the escalator, and so on. This could increase accessibility by aiding people who cannot do these operations or who could function better in the adapted environment.

5 ACCESSIBILITY MAPS

Collected information and testing of accessibility could be managed by creating *accessibility maps*. An accessibility map adds to an ordinary geospatial map a layer of information regarding accessibility. Formally, an accessibility map contains geospatial objects and an accessibility function f_{aid}. Let D be a set of disabilities, L be a set of locations, T a set of times, C a set of records with contextual information (like weather conditions or sunlight intensity), A a set of actions, I a set of textual information snippets and V a set of visual symbols, then $f_{aid} : D \times L \times T \times C \rightarrow A \cup I \cup V$ maps a given tuple of disability, location, time, and context to an action, an information snippet or a representing map symbol. For example, for a location of a train station and the constraint of being in a wheelchair the function might return the information "no access". For a lobby of a building and a hearing impairment disability, the action might be notifying the doorman about the disability and collecting data about the success of accessing the building. Note that the map is temporal and dynamic, i.e., changes over time. Being dynamic, including actions and addressing different types of disabilities are novel features in comparison to static accessibility maps.

Classification of accessible places could be updated and improved constantly based on collected data, see Fig. 1. The maps could then be used for creating contextual filters and simulations in virtual worlds like the metaverse. Accessibility maps could specify the AID actions for wearables, according to the disability, location, time and context. The maps would provide the required information for executing ambient intelligence on smartphones and other devices.

6 DISCUSSION

In the past, accessibility and inclusion issues were not prioritized by developers. Combined with absence of supporting technology, limitations of users were ignored. But when mobile apps and wearable technology are becoming intrinsic to high-quality of life, developers should strive to provide the same experience to all users. Thus, we suggest a novel combination of technologies to allow developers experience user limitations and test their applications in scenarios that imitate disabilities. We suggest the use of contextual filters in real life and in virtual worlds like the metaverse as a way to simulate different usage scenarios. Recent advancement in GPUs and virtual reality make such simulations possible. Data collection based on ubiquitous computing could fuel ambient intelligence to create accessibility maps, where information, recommendations and actions could be provided to application developers, testers and users. This information could be used by devices that facilitate access to places and systems. Our vision provides a variety of research challenges, including study of contextual filters, data collection for accessibility maps, and privacy-preserving use of data in ambient intelligence. A fundamental challenge is creating a digital twin of the setting by accurately representing real-world settings and interactions in virtual worlds, for creating advanced testing environments, and developing tools like WAI-ARIA (https://www.w3.org/TR/wai-aria-1.1/) for geospatial applications and mobile devices.

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