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Breaking Data Barriers: Advancing Web Data Accessibility for the Visually Impaired

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Abstract

In today's era of technology there is a belief in the importance of making data and information available to everyone. However, this accessibility remains a challenge for a group of people; those who are blind or visually impaired. The concept of accessible data representation is the focus of this thesis and its relevance to the unique difficulties faced by this community. It will delve into every aspect of data accessibility from how it's initially communicated to the intricate world of interaction.

To start we conduct an examination of the current status of data accessibility. This examination explores the aspects of the issue including how data is used in different settings like homes, public spaces and workplaces. We analyze types of data ranging from time-based data to geographical information uncovering the complexities involved in making these diverse forms of data accessible to people, with visual impairments. Throughout our investigation we emphasize both the strengths that already exist in this field and the key obstacles that hinder accessibility.

The principal aim is to deconstruct the complex network of obstacles impeding the full assimilation of visually impaired persons into the digital age. The objective of this study is to uncover obstacles that prevent this community from having seamless access to data by critically evaluating current design techniques. Moreover, it aims to create a road map for developing a more inclusive digital world in which data is not just available but also sensitive to the specific needs of people who are blind or visually impaired.

This research strives to tackle two challenges. First, it seeks to shine a light on the intricate obstacles that hinder blind and visually impaired individuals from reaping the full advantages of the digital world. Second, it envisions an inclusive digital space where information is not just accessible but also meticulously crafted to suit the diverse needs of people with blindness or visual impairments. By delving into these issues and working toward ensuring all data - numerical, graphical, or textual - is truly universal and open to everyone, this study aims to spark positive change.

Keywords:

Accessibility, Assistive Technology , Blind and Visually Impaired, Data Interaction, Data Representation, Web Accessibility, User-Centered Design.

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1. Introduction

In a time characterized by an unrelenting flood of data, when the digital domain acts as a massive storehouse of information, experience, and knowledge, accessibility assumes a new meaning. The Internet's widespread reach has led to an explosion in data, which has completely changed how we access, share, and use information. However, this data-driven revolution has also unintentionally planted the seeds of exclusion for a significant portion of our society, the visually impaired. This is despite the fact that technology has brought about an era of unparalleled connectivity and empowerment [1].

Imagine having only a screen reader or a braille display to guide you as you navigate the infinite web, a maze of webpages, databases, and interactive content. While the digital world is awash in pictures, graphs, charts, and intricate data representations, blind people face a daunting obstacle since their access to this vast array of information is restricted to a few lines of text or auditory clues. This thesis aims to solve the significant difficulty of the disparity that exists in the digital sphere between individuals who are visually able and those who have visual impairments [2].

This thesis explores the field of accessible data representation emphasizing how to make data more accessible to blind and visually impaired people. We embark on this journey with a steadfast dedication to inclusively, a commitment that has only grown more important in a time characterized by the widespread use of digital technology [3].

Data accessibility presents a complex problem to those who are visually impaired. It goes beyond transferring information in a manner that can be heard or seen with the senses. It also goes into the area of interaction: how can people who are blind or visually impaired interact meaningfully and effectively with data? Think about how frustrating it would be for a blind professional to read complicated financial reports, or for a blind student to try to understand a complicated mathematical graph. How can we enable them to actively engage with data, get insights from this, and modify this to meet their specific requirements rather than merely grant access to this [4].

This thesis has a moral and ethical motivation as well as an intellectual undertaking. Its goal is to democratize data so that everyone may benefit from what the digital era has to offer, irrespective of their visual ability. It incorporates the spirit of universal design [5], supporting equal access to the digital sphere, the dismantling of barriers, and the empowerment of long- underserved groups.

We shall travel over a terrain marked by a multitude of data kinds as we work through this thesis, from textual data to spatial and temporal data. We will look at a variety of usage cases, such as the cozy confines of one's home, the busy environment of a job, and the busy streets of public areas. We will examine the technological solutions that have been created, considering the advancements that have been accomplished as well as the ongoing difficulties. We will pinpoint the gaps in the data translation process for blind people by using an inclusive lens, and we'll start a design phase where we think of creative ways to close these gaps [6].

Our dedication to cultivating a more accessible digital world is exemplified through a focused exploration of established design methodologies in this study. This deliberate approach allows us to contribute meaningfully to the discourse surrounding data accessibility for individuals who are blind or visually impaired. The study aims to distill key principles and best practices from a comprehensive review of established methodologies, presenting a refined understanding that can serve as a valuable resource for shaping inclusive digital experiences [3].

This thesis is a call to action, an exploration, and an advocate. It symbolizes the coming together of design, technology, and empathy, directing these energies to light the way for a more inclusive digital future. Together, we will explore the intricacies, subtleties, and potential applications of accessible data representation for individuals with visual impairments, acknowledging that this is a quest for justice and equality in the digital age rather than just a question of design and technology.

2. Literature review

2.1 Understanding Data Accessibility for Visually Impaired Individuals

Accessing, interpreting, and interacting with data has become essential in the digital age, influencing our experiences in the workplace, in school, and in our personal lives. Data is everywhere, influencing decisions and deepening our comprehension of the world through everything from reading news articles to deciphering intricate financial reports. However, the digital environment, with its complex data representations, presents a significant barrier to accessibility and comprehension for those who are visually impaired [1].

In all of its forms, data is usually presented using a visual approach. Information is conveyed using graphs, charts, maps, pictures, and other visual elements that use color separation, spatial layouts, and visual signals. Although these visual signals are useful for sighted people, people with visual impairments find them to be a significant hurdle. For this demographic, accessing the digital sphere involves overcoming significant differences in the way data is presented and made accessible [7].

Individuals who are visually challenged, which includes those with different levels of visual impairment, encounter particular difficulties when trying to make data accessible. These difficulties go beyond the limitations posed by using screen readers, braille displays, or navigating websites. The basic challenge of converting visual data into understandable and meaningful aural or tactile representations is at the core of the matter [1]

Because visual representation is intrinsically spatial, sighted people may understand relationships and patterns just by looking at how items are arranged on a page or screen. For instance, the arrangement of data points, axes, and labels in charts and graphs helps to convey patterns and insights. Geographic information is conveyed through maps by placing features and regions next to each other. Through the use of visual symbolism, diagrams, and schematics help to explain difficult material [8].

People who are visually impaired use their other senses—hearing and touch, in particular, to perceive their surroundings. This change in sensory perception calls for creative methods of making data accessible. The most popular assistive device, screen readers, translates text into synthesized speech and serves as a vital link between blind users and digital material. However these screen readers are not always able to decipher the complex visuals in data representations [10], [11].

Figure 2.1 Assistive Technology - Screen Reader [9]

Screen readers' limitations become apparent when they come across intricate graphs or charts. Visual element descriptions, such as "a line graph with an upward slope" or "a bar chart with varying heights," could give some insight into the data, but they are insufficient for a whole comprehension. Furthermore, the interpretability of these explanations may differ based on the screen reader being used and the user's level of experience with data visualization ideas [12].

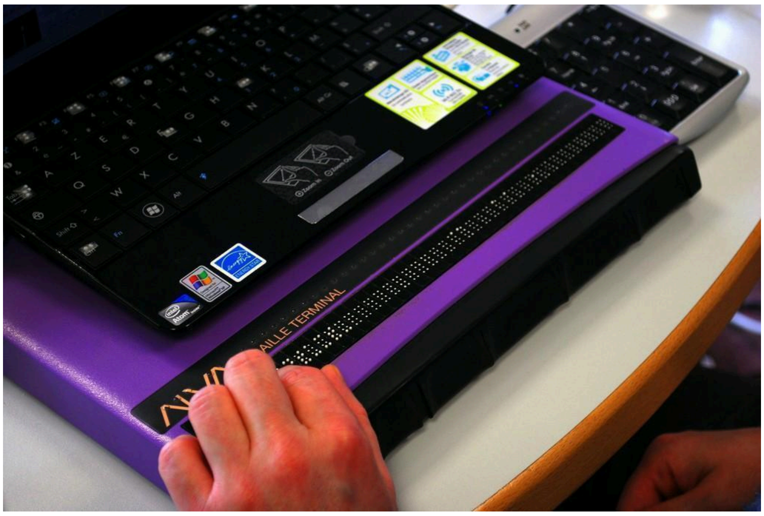

Figure 2.2 Braille Display [13]

Another form of assistive technology is the braille display, which provides tactile feedback by turning text on the screen into braille characters. Braille displays work well for textual content, but they are less suited for displaying sophisticated graphics or maps that depict geographical data. Braille's haptic quality limits how much information can be displayed at once, necessitating a lot of scrolling or exploring [12].

One of the biggest challenges the braille reading community is now facing is the length and complexity of the publication process. When a new book is published, sighted readers might not receive it for weeks or months if it is made available in braille at all, especially if it is a long textbook. Braille is inherently much larger once printed than it was when it was first written since it has a lower information density than normal type [14].

In order to address these issues, APH collaborated with HumanWare to integrate this new technology into the Dynamic Tactile Device, or Monarch, a large-scale braille reader and writer [14].

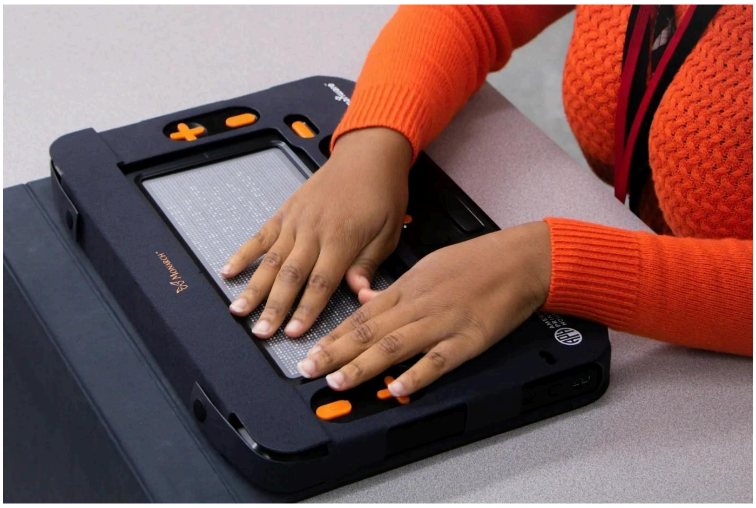

Figure 2.3: APH/Humanware Monarch [15]

The graphic capacity is a significant advancement. The Monarch's ten lines, each with 32 cells, allow users to read the device more like they would an embossed or printed braille page, in contrast to many previous braille readers that only had one or two lines. Furthermore, as demonstrated by basic graphics can be displayed using the continuous pin grid, which is Dot's reference device[15].

When working with information that is color-coded, the difficulties become even more complex. Blind users are unable to understand visual signals like color distinction, which provide data representations crucial context. Similar to this, those who rely more on touch or hearing than on vision have a fundamentally different understanding of spatial organization.

Novel strategies have emerged in the field of data accessibility for the blind and visually impaired to overcome these issues. By transforming data into auditory representations, sonification, for example, provides a viable answer by enabling users to "listen" to data patterns. Sonifications that are well-designed can offer significant aural clues that communicate information more effectively than text-to-speech conversions alone [16].

The fields of 3D printing and tactile graphics offer yet another line of inquiry. These technologies allow data visualizations to be created in a tactile format, allowing users to explore spatial data through touch. Nevertheless, given the volume of digital data that is readily available online, applying tactile graphics is time-consuming and not always feasible.

Universal design principles have been gradually adopted in the quest for data accessibility for the blind and visually impaired. This strategy minimizes the need for retroactive adjustments by emphasizing the creation of digital content and user interfaces that are fundamentally accessible to all users [18]. It entails a comprehensive rethinking of the presentation and interaction of data in the digital realm, with a focus on inclusion from the very beginning of design.

Even with these noteworthy developments, there are still a lot of difficulties, especially when working with dynamic and interactive data representations. There is always space for innovation and improvement because current systems frequently struggle to provide meaningful access to data interactions and investigations.

The literature on data accessibility for people who are unsighted or visually impaired is a dynamic and ever-evolving field that reflects the ever-changing goals of fair access and the shifting terrain of digital data representation. In an effort to address the issues, offer creative solutions, and eventually forward the cause of making data universally accessible and understandable, regardless of one’s visual ability, this thesis contributes to the continuing conversation.

2.2 Challenges Faced by the Visually Impaired

Having the ability to access and engage with data is becoming more and more important in a world where digital information is growing at an unparalleled rate. But this data-rich digital environment poses a daunting set of obstacles that prevent those with visual impairments from participating and being included. This section explores the many obstacles that people who are blind or visually impaired experience while attempting to use the digital world [18]

2.2.1 Visual Information as a Barrier

Visual information—text, photos, videos, charts, graphs, maps, and many other visual representations of data—is the cornerstone of the digital world. Although these components successfully communicate information to seeing users, blind or visually impaired people find them to be a substantial impediment. Visual cues like color, spatial arrangement, and complex graphical designs are essential to the processing of visual information. Those who rely on their touch or aural senses to perceive their environment are unable to perceive these signs [16].

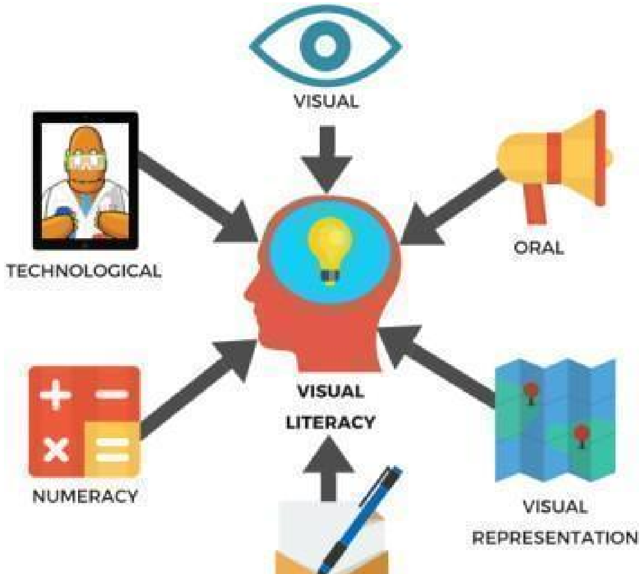

Figure 2.4 Modes of Visual Information [19]

As such, the information included in visual elements is generally inaccessible to a blind person interacting with a web page, document, or any other digital content. For instance, consider complex data visualizations like graphs and charts embedded in educational materials or re- ports. Although technology such as screen readers and braille displays has been created to translate text into tactile braille or synthesized voice, respectively, they are not without limits. While screen readers excel at deciphering text and providing speech access to it, they often struggle with interpreting the nuances of more intricate data visualizations. Similarly, braille displays work effectively for displaying text, yet they prove inadequate when it comes to rendering complex data visualizations or conveying spatial information. Consequently, critical information is often understood in fragments, and data representations remain largely out of reach for individuals with visual impairments [16].

2.2.2 Web Content Accessibility Limitations

The manner that web content is structured and designed can add to the difficulties that un-sighted and visually impaired people experience. Accessibility guidelines, particularly the Web Content Accessibility Guidelines (WCAG), have been very beneficial to the cause of web accessibility. These recommendations provide ideas and methods for improving the readability, functionality, and comprehension of web material for a wide range of users, including those with impairments. However, there are significant differences in how these principles are applied on different websites and digital platforms [20].

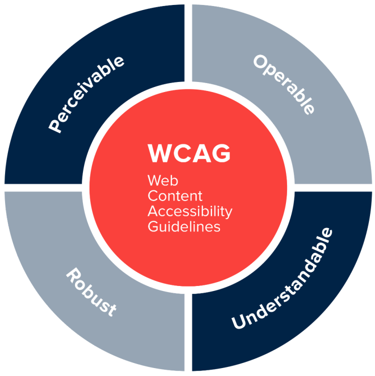

Figure 2.5 Web Content Accessibility Guidelines (WCAG) [21]

Although WCAG offers guidance on how to make graphical content accessible, it is not as clear on data representations. There aren't many detailed instructions in the standards to make sure that graphs, and charts are sufficiently described for those who cannot see. Web developers and content producers are left without clear guidelines on how to ensure equitable access to data-rich content due to this gap in guidance. As a result, data representations continue to be a major obstacle for partially sighted or visually impaired people, who are frequently forced to interpret data using less effective methods like vocal descriptions or written summaries [22]

2.2.3 Complex Data Interpretation

An era of data driven, decision making has been initiated in by the digital age, when access to large data sets is essential for a variety of life decisions, including civic involvement, education, and work. Working with data might be especially difficult for people who are blind or visually challenged. Although speech can be generated from textual data, comprehending graphical data is a more complex process [23].

Think about a visually impaired student taking a statistics course. When given a graphical depiction of the data, they could find it difficult to understand the underlying relationships, trends, and patterns. This problem is widespread and affects many domains, including finance, where visually impaired workers may struggle to understand complex financial reports or market patterns illustrated by charts and graphs [23]

In summary, being able to derive meaning from data visualizations is important for empowerment and engagement in a data-driven society, not only for accessibility. In the digital age, when knowledge and insights are communicated through data more and more, the visually impaired continue to be at a major disadvantage if this difficulty is not successfully addressed.

In conclusion, visually impaired people confront significant and varied problems in the digital sphere. These obstacles include the inherently visual nature of the information, the limitations of assistive devices, the discrepancies in the accessibility of web material, and the challenges associated with deciphering complicated data. To overcome these obstacles, a comprehensive strategy is needed, one that gives visually impaired people the tools they need to interact with and make sense of the abundance of data that the digital age has to offer. The goal of this thesis is to clarify these issues and offer creative solutions that support everyone's inclusion in the digital world, regardless of visual ability.

2.3 State of the Art in Data Accessibility for the Blind and Visually Impaired

The environment of data accessibility for the blind and visually impaired is dynamic and ever- changing, with ongoing issues coexisting with advancements. This section delves further into the current technology and solutions that have influenced this user group's ability to access data. Comprehending the existing situation is essential in order to pinpoint any shortcomings and possible avenues for enhancement. In order to define the state of the art in data accessibility, we will examine the following essential components: Web content accessibility guidelines (WCAG), Sonification of data, Tactical graphics and 3D printing.

2.3.1 Web Content Accessibility Guidelines (WCAG)

A keystone in the pursuit of digital inclusion is the Web Content Accessibility Guidelines (WCAG). A complete framework for web accessibility is provided by the World Wide Web Consortium (W3C) principles, which guarantee that online material is readable, navigable, and comprehensible by a wide range of users, including those with impairments. Even though their primary focus is on text, WCAG has played a significant role in advancing accessible web design techniques [22].

Nevertheless, WCAG's scope is constrained in terms of data accessibility. Screen readers and braille displays can be used to make textual content accessible, but data visualizations such as graphs, charts, and maps provide a different kind of difficulty. These visual components frequently depend on color, spatial arrangement, and intricate graphic patterns, all of which are incomprehensible to blind users by design. Consequently, WCAG is unable to offer clear instructions on how to make data visualizations accessible. Further standards and procedures to close this gap are therefore needed [22].

2.3.2 Sonification of Data

Sonification, the process of converting data into audible sound [24] is one potential direction in the quest for data accessibility. Sonification is a non-visual method of data representation that enable also those with visual impairments to understand data using auditory cues. By utilizing audio signals, this method offers an alternative to the visual medium. Pitch, rhythm, and volume changes can be used to represent data, providing a distinct and possibly more thorough comprehension of the relationships and patterns within the data.

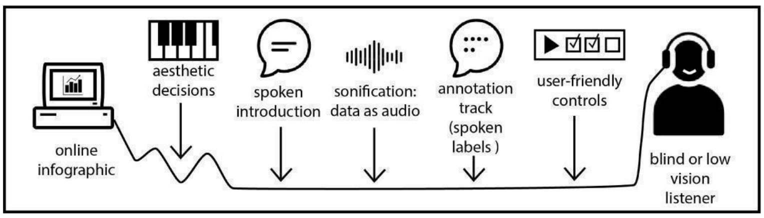

Figure 2.6 Sonification of data for visually impaired [26]

This image is thorough examination of sonification seeks to give readers a full grasp of the steps data takes to become accessible to blind or visually impaired users, highlighting the significance of user-centric design and careful planning.

Online Infographic

This section explores the benefits and problems that come with using infographics to deliver information online. It studies how visual features might be transformed into audio representations, making digital infographics accessible to those with visual impairments.

Aesthetic Decisions

This section looks at how sonification design takes aesthetics into account and shows how data presentation through audio can be both useful and beautiful. It addresses how design choices affect how people who rely on auditory input perceive the system as a whole.

Spoken Introduction

Setting the context for data sets requires a spoken introduction. To make sure users comprehend the facts they are going to examine, this section examines efficient methods for introducing information through spoken narration.

Sonification of Data as Audio

This section, which centers on the main topic of the chapter, examines different methods and strategies for converting visual data into audible representations that make sense. It goes over the fundamentals of sonification and how various forms of data can use it to efficiently communicate information through sound [27].

Annotation Track (Spoken Labels)

Spoken labels must be included in order to provide data items context and significance. This section explores the significance of annotation tracks, in which spoken labels improve users' understanding of data points and facilitate their navigation and interpretation of the information displayed [27].

User-Friendly Control

The user interface and control aspects of sonification tools are covered in the concluding chapter. It investigates how users can customize their experience and make the tools more approachable by interacting with and controlling the sonification process. This is especially useful for individuals who have visual impairments.

Sonification has shown potential in a number of domains, including as science, accessibility, and education. Sonification techniques have been investigated by researchers and developers to improve data accessibility for professionals and students who are visually impaired. For instance, intricate scientific data can be rendered into soundscapes that communicate subtle information, such as astronomical measurements or molecular structures. In order to help blind users discover and comprehend geographic information, sonification has also been applied to the depiction of geographical data. Maps and spatial data have been transformed into audio formats [24]

Even while sonification represents a substantial improvement in data accessibility, its full potential is still untapped. There are still issues with creating efficient sonification techniques, especially when trying to translate various kinds of data into useful audio representations. For example, there are particular difficulties when converting complicated data visualizations or rich spatial information into audio. Standardizing sonification processes and investigating methods to improve data interaction for the blind are the focus of ongoing research. Recent developments, for instance, have demonstrated encouraging outcomes in the sonification of geographic data, converting maps and spatial information into unique audio cues. Notwithstanding these obstacles, sonification's potential to significantly increase data accessibility for the blind and visually impaired continues to be an intriguing research topic.

2.3.3 Tactile Graphics and 3D Printing

The emergence of 3D printed data visualizations and haptic graphics is another significant advancement in data accessibility. With this method, data representations can be changed into tangible, tactile formats that can be felt. In educational settings, tactile graphics are especially helpful because they give blind students studying courses like mathematics, chemistry, or geography, which largely rely on pictorial information, a hands-on experience.

Figure 2.7 Tactile map for visually impaired [28]

The ability to create haptic data visualizations has been significantly enhanced by the development of 3D printing technology. 3D printing has been used in experiments by researchers and educators to create complex tactile maps, graphs, and charts. Through more immersive and interactive means, blind people can explore and understand facts thanks to these physical representations. For instance, a blind learner can learn about geographical features and elevation changes by looking at a 3D-printed topographical map [29].

Although 3D printing and tactile graphics have significantly improved data accessibility, issues with scalability and ease of production still exist. Making haptic data representations is frequently a labor-intensive procedure that calls for specific knowledge and resources. Furthermore, these techniques work best with static data representations; Usually they are not as applicable to dynamic or real-time data [24].

In summary, innovation and advancement have raised the state of the art in data accessibility for the visionless and visually impaired, but more studies and development is still required. Although they provide a solid basis for textual material that is accessible, web accessibility standards like WCAG are unable to fully handle the intricacies of data visualizations.Tactile graphics and three-dimensional printing provide tactile engagement, while sonification provides an audio approach to data accessibility.

2.4 Tabular Data Accessibility

2.4.1 Audio Conversion of Table Structure Software

For visually challenged users, text-to-speech software is essential since it enables them to access and understand tabular data verbally. The content of tables, including headers, data, and other pertinent information, can be heard by blind people by translating text into spoken language. This increases accessibility to the data and promotes a more inclusive understanding.

2.4.2 Audio Conversions of Descriptive Headings

Table heads that are both clear and descriptive help individuals with visual impairments navigate and understand the content. These categories can be announced by screen readers, giving users an organized rundown of the table's structure. When working with tabular data, blind people can experience a more seamless and effective experience when headings are formatted correctly.

2.4.3 Braille Conversions

Converting tabular data in Braille forms guarantees direct access to the information without relying on aural signals for visually impaired users who can read Braille. This approach pro- vides a tactile substitute for understanding and utilising tables, designed to especially fulfil the needs of individuals who use Braille.

2.4.4 Multiple Formats

Multiple data formats are available to meet the various needs and preferences of users who are blind or visually impaired. Braille may be the preferred method of information for certain people, whereas text-to-speech may be preferred by others. Giving visually impaired individuals a choice of formats allows them to choose the one that best fits their chosen way of consuming information.

2.4.5 Interactive Voice Response (IVR) Systems

To enhance the accessibility of tabular data for visually impaired users, novel technologies such as Interactive Voice Response (IVR) systems have been devised for phone-based interactions. These technologies guarantee efficient table exploration via spoken instructions, offering a visually impaired person's inclusive interface. For example technologies like Zendesk, Genesys, Five9, Nice inContact are leading in these service. A well-implemented IVR system can enable users to navigate and get tabular information effortlessly by interacting with a spoken interface. This technology breakthrough not only solves the problems with conventional visual approaches, but it also shows how inclusive design may use spoken interactions to improve information accessibility across a range of communication channels.

2.4.6 Accessible Spreadsheet Tools

By utilizing accessible spreadsheet technologies, spreadsheet documents can be navigated and tabular data interpreted by visually impaired users with ease. Ensuring accurate comprehension of the information supplied in the table is made easier for screen reader users by providing meaningful cell labels and appropriate organization. Those with visual or cognitive disabilities who utilise Microsoft 365 .

3. Analysis and Weaknesses in Data Accessibility for Visually Impaired

An extensive examination of the current environment is essential if we are to improve data accessibility for the unsighted and visually impaired. The goal of this analysis is to identify the primary flaws preventing this user group's smooth data translation and engagement. In order to achieve this, we examine assistive technology and analyze data accessibility from a variety of angles, classifying different data kinds and investigating a range of use cases. In-depth review of the analysis and the discovery of significant flaws are covered in this part [28].

3.1 Categorizing Data Types for Accessibility

3.1.1 Plain Textual Information

Digital information is built upon textual information. For those who are blind or visually challenged, this type of data is the most readable since it uses alphanumeric characters and textual material. Blind people can very easily access textual information with text-to-speech technology, braille displays, and screen readers. But flaws do appear, even in one area that seems simple.

Structured Textual Information

Tables, lists, and headings are common formatting components used in textual data. Although certain formatting cues are physically obvious, screen readers may have trouble understanding them. The visual structure of a document may not be well conveyed by screen readers, providing blind people with a fragmented view. For instance, when read aloud by a screen reader, a well-designed table might not make sense, which would compromise the reader's ability to understand the data as a whole.

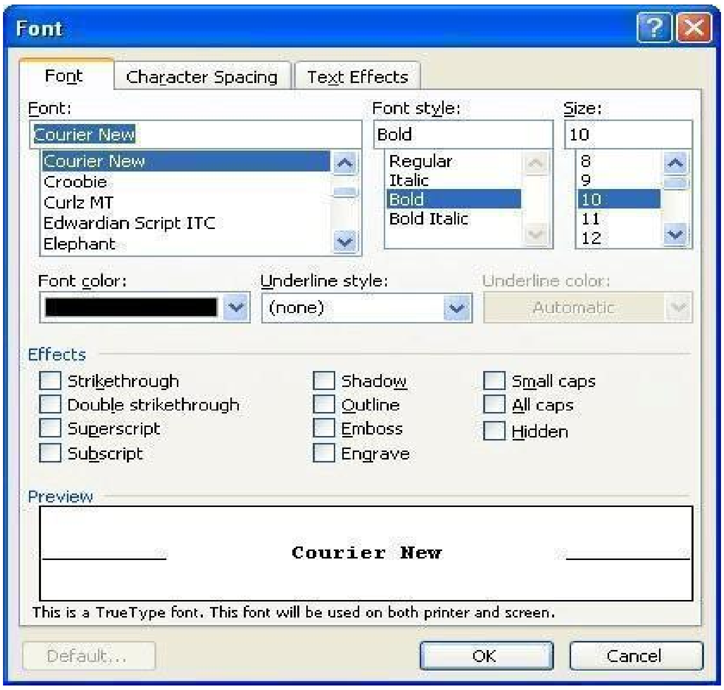

*Figure 3.1 Complex Formatting for Textual Data [*31*]*

Mathematical Formulas

Textual data often contains mathematical notations and equations in both professional and educational environments. Accurately decoding these mathematical parts can be difficult for screen readers. It's possible that the accuracy needed for a thorough comprehension is lacking in the interpretation of mathematical symbols and processes.

English	Math
is, yields, will be	=
what number, how much (look at question)	"x" (or any variable)
in addition to, added to, increased by	+
sum of x and y	$x + y$
difference of x and y	$x - y$
product of x and y	$x \times y$
quotient of x and y	$x \div y$ or $\frac{x}{y}$
opposite of x	$-x$
ratio of x to y	$x \div y$ or $\frac{x}{y}$
a number n less 3	$n - 3$
a number n less than 3	$3 - n$
a number n reduced by 3	$n - 3$
of	times
p percent	$\frac{p}{100}$, or move decimal left 2 places
half, twice	$\frac{n}{2}$, $2n$
consecutive numbers	Let n = first number, $n + 1$ = second number, $n + 2$ = third number...
odd/even consecutive numbers	Let n = first number, $n + 2$ = second number, $n + 4$ = third number... (Note: even if you are looking for odd consecutive numbers, use n, $n+2$, $n + 4$...).
average of x, y, and z (and so on)	$\frac{x+y+z+...}{\text{(how many numbers on top)}}$
x per y, x to y, x over y, x part of y	$x \div y$ or $\frac{x}{y}$ Example: number of girls to total people can be represented by $\frac{\text{girls}}{\text{total}}$.
x per y, as in x "for every" y	Multiplication, or $x \times y$. Example: if you drive 50 miles per hour, how many miles will you drive in 5 hours: 250 miles.
y increased by $x\%$	$y + \left(y \times \frac{x}{100}\right)$
y decreased by $x\%$	$y - \left(y \times \frac{x}{100}\right)$
y is at least (or no less than) x	$y \geq x$
y is at most (or no more than) x	$y \leq x$
y is between x and z	$x \leq y \leq z$ (inclusive) $x < y < z$ (exclusive)

Figure 3.2 Simple Mathematical Notations [32]

3.1.2 Structured Data

Structured data can be represented as tables or through visual representations for example, charts. Visual representations frequently are based on spatial arrangements and visual signals that are intrinsically unavailable to the blind.

Complex Data Representations

Tables, charts, and graphs are used for representing numerical data. The complex relations between data. Although assistive technology can communicate numbers in an aural format, they frequently have trouble expressing the visual correlations found in the data. For example, when converted to an audio format, a meaningful scatter plot that presents data may not convey any more.

Visual Cues

Visual cues like color coding and spatial placement are frequently used in numerical data to convey information. Screen readers and braille displays usually aren't able to handle these cues. Blind people may only grasp a limited amount of data because the tools they use are unable to transcript important subtleties that are coded in these visual signals.

Visual Representations

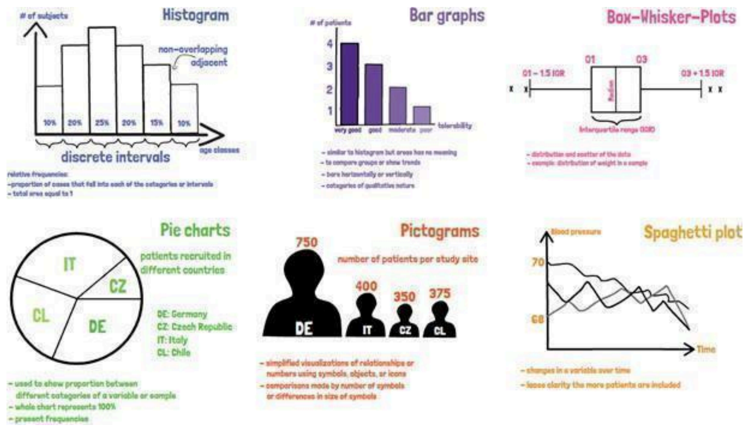

Figure 3.3 Complex Formatting for Textual Data

A variety of visual representations, including maps, graphs, charts, and spatial diagrams can be used for representing data. Because these representations are mostly visual, it might be difficult for blind people to access and understand them.

Visual components such as shapes, lines, colors, and spatial relationships are essential to graphic data. These components make it easier to comprehend data trends and patterns, which are generally unreadable by visionless people. Therefore, converting graphical data into an understandable and instructive manner continues to be a significant difficulty.

Information Density

Often, graphical data may communicate a great deal of information in a small area. It may be difficult for screen readers and other assistive technology to give a clear, thorough explanation of complicated graphical data. The auditory data density limitation.

Interactivity

Particular care must be taken with data that varies in time or because of user interaction. It is difficult for the blind to perceive and interpret data that is updated in real-time, particularly when there are visual cues or feedback systems involved.

Adaptive fixes that address each type of data is necessary to address these shortcomings in data accessibility. Textual data is relatively accessible, but solutions for sophisticated formatting and mathematical notations must be customized. In order to establish a more inclusive digital world for the visually impaired, we will examine alternative solutions for each data category in the parts that follow in this thesis.

3.2 Contexts of Use for Data Accessibility

Data accessibility for unsighted and visually impaired people is not limited to the digital realm; it permeates a variety of use settings that influence these people's everyday experiences. In order to arrive at a comprehensive comprehension of data accessibility, it is essential to investigate the complex nature of these settings. This section explores the subtleties of data accessibility in three contexts: public spaces, workplaces, and home use. It also highlights the benefits and problems associated with each setting. Accessibility and usability issues that people with regular eyesight and blind people have with websites and mobile applications.

3.2.1 Home Use

Accessibility in Everyday Life

Figure 3.4 Smart Home Gadgets

For many people, especially the visionless and visually impaired, the home is the center of their everyday lives. Data accessibility in home settings is critical for everything from personal financial checking to recreational activities. The home environment for visionless people has been completely transformed by digital books, talking thermostats, and smart home gadgets that are accessible. Nonetheless, there are still serious flaws in the conception and operation of commonplace electronics. Digitally interfaced cooking appliances, for instance, could not include the accessibility features needed for self-sufficient cooking. Moreover, visually impaired people's options for amusement are limited by the accessibility issues associated with digital entertainment, such as video games and streaming services [32].

Challenges in Daily Data Handling

While reading recipes, creating a household budget, and using electronic books are everyday tasks, they pose unique data accessibility issues. For the purpose of deciphering textual data, such as financial accounts or digital novels, screen readers and braille displays are useful instruments. But when working with graphical data, such as budget charts or picture recipes, flaws appear. These difficulties highlight the necessity of easily readable forms for data about the home [32].

Independence and Personal Information Management

Blind individuals aspire to maintain independence in their homes. Accessible data plays a pivotal role in this quest. For instance, accessible navigation and labeling systems allow visionless individuals to move freely within their homes. Furthermore, personal information management, including calendars and to-do lists, is essential for daily organization. Weaknesses in these areas are evident when digital systems lack voice commands or tactile interfaces.

3.2.2 Public Contexts

Navigating Public Spaces

Public contexts include a broad spectrum of settings, including transit hubs, museums, government buildings, and retail stores. In these environments, having easily accessible data is essential to promoting engagement, interaction, and navigation. Public information must be presented in ways that are accessible to visually impaired people, including signage, ticket kiosks, and public display systems. When public information systems are not created with accessibility in mind, vulnerabilities occur. For instance, the touchscreens on public transit kiosks may not include tactile or audio interfaces, which makes it difficult to plot a route and buy tickets [33].

Accessible Museums and Cultural Institutions

A plethora of information can be found in museums, galleries, and other cultural establishments in the form of interactive displays, audio guides, and exhibit descriptions. Even if a lot of cultural institutions have improved the accessibility of their material, there are still issues with interactive displays' inclusivity. These might mostly rely on touchscreens or visual material, which would limit how involved blind visitors can be [34].

Digital Accessibility in Retail and Service Industries

The retail and service sectors are becoming more and more dependent on digital technologies for client interaction. Notable flaws include digital menus in restaurants, online purchasing platforms, and inaccessible point-of-sale systems. Blind people's dining and shopping experiences may be hampered by their incapacity to independently obtain information.

3.2.3 Work Contexts

Employment and Data Accessibility

The work environment is one where having access to data is essential for both career advancement and job effectiveness. In their professional lives, visionless people deal with data in a variety of ways, from data analysis to teamwork and communication. One important consideration is whether or not the workplace software is compatible with assistive devices. When specialized or proprietary software used in work environments is not made to work with screen readers or other assistive devices, it is flawed. This may restrict the access of unsighted people to important information and software.

Office Technology and Meeting Accessibility

Utilizing office equipment like printers, photocopiers, and conference room supplies can be very difficult at times. Inaccessible office equipment may require sighted coworkers' assistance to operate, preventing autonomous work. Inadequate accessibility measures, such inaccessible presentation materials, can also hinder blind people's ability to collaborate with others [35].

Data Analysis and Interpretation

Data analysis is a common task in professional settings, but it can be challenging for blind people to do. When statistical software and data visualization tools don't have easily available features, they become weak in this situation. Lack of capacity to work with and understand complicated data might hinder one's ability to do their job and limit one's career options [36]. In conclusion, ensuring data accessibility for the blind and visually impaired is a complex process that takes place across a range of use cases. The settings that affect blind people's lives and experiences range from the coziness of their own homes to the busy streets of public places and the dynamics of the job. Promoting independence, involvement, and diversity in these situations requires identifying and fixing flaws in data accessibility. In order to increase data accessibility and improve the lives of blind and visually impaired people in these many situations, the next sections of this thesis will investigate solutions and prototype development to address these deficiencies.

3.3 Assistive Technologies in Data Accessibility for Visually Impaired

Figure 3.5 Assistive Technology [37]

One essential element of the dynamic ecosystem that aims to improve data accessibility for people with visual impairments is the incorporation of assistive technology and devices. Technologies that are transformative aids include variable-speed tape recorders, audio books, graphic organizers, word processing systems, alternate keyboards, and outlining tools. Through non-visual sensory inputs, these assistive technologies enable users to engage with and comprehend data. For example, word processing software offers audio feedback, graphic organizers and outline tools make information structure easier, and different keyboards with tactile feedback improve the typing experience. Speech recognition software allows data input without requiring hands-on assistance, while audio books provide an engaging and easily accessed method for textual content consumption. Tape recorders with variable speeds allow for personalized playback choices, meeting the needs of different pace preferences. Through the integration of these assistive technologies, data becomes not only accessible but tailored to the diverse needs of visually impaired individuals, fostering a more inclusive and equitable information environment [38], [39].

3.3.1 Hardware based Techniques

Screen Readers

Screen readers are computer programs that translate text and visual content displayed on a screen into audible speech or other non-visual output. When it comes to data accessibility in digital environments for the visually impaired, these technologies have been indispensable. They make it possible for blind individuals to engage with software interfaces, browse websites, and access textual material [24], [38].

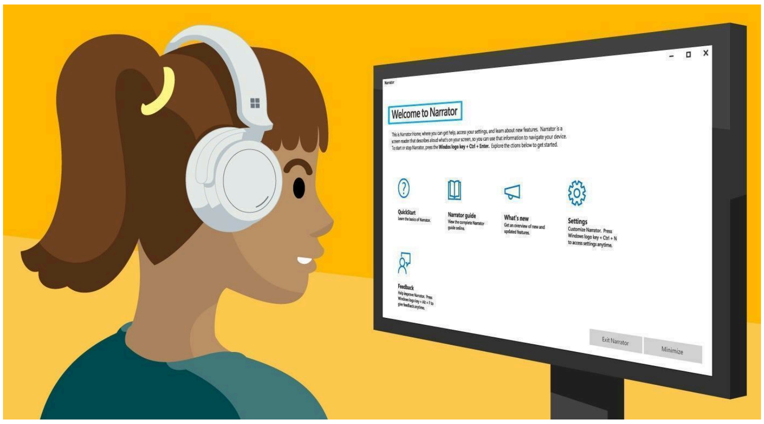

Figure 3.6 Screen Readers [40]

Figure 3.7 Braille Display [13]

The possibilities for developing haptic data visualizations have increased with the advent of 3D printing technology. It makes it possible to create complex, three-dimensional data representations. These tangible models offer a more immersive method of data exploration by putting the user's hands on the information [38].

Tactile Graphics

Raised lines and textures are used to generate tactile graphics, which are embossed depictions of pictures, graphs, charts, and maps. By giving consumers tactile access to graphical data, they enable touch exploration of these representations. In educational contexts, tactile graphics have proven invaluable in helping students learn difficult subjects like geography and arithmetic.

3D Printing

The possibilities for developing haptic data visualizations have increased with the advent of 3D printing technology. It makes it possible to create complex, three-dimensional data representations. These tangible models offer a more immersive method of data exploration by putting the user's hands on the information.

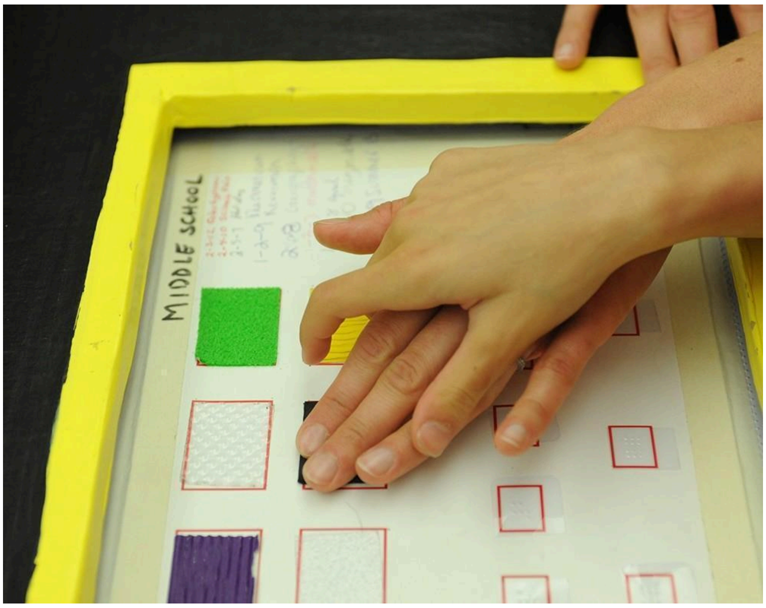

Figure 3.8 Tactile Graphics For Students Who Are Visually Impaired [42]

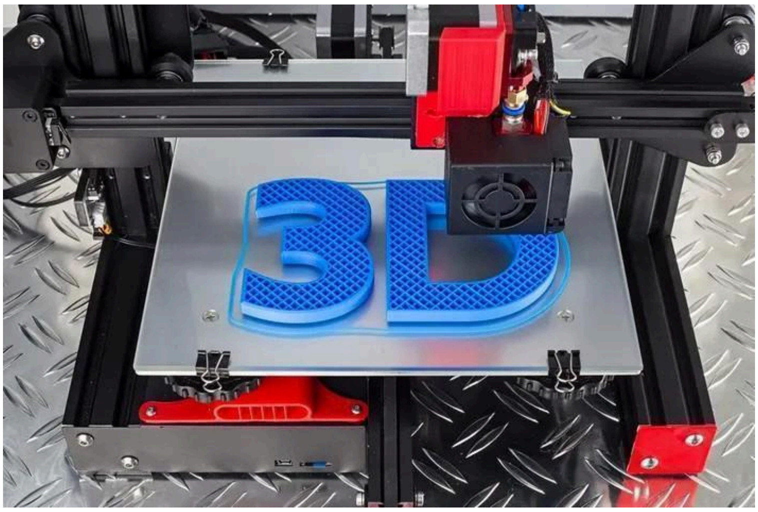

Figure 3.9 3D Printing For Data Representation [43]

Challenges

Producing tactile graphics and 3D-printed objects can be labor-intensive and require specific knowledge. Dealing with big datasets or real-time data presents a barrier to these technologies' scalability. Furthermore, tactile visuals and 3D models may need a lot of manual labor to prepare, which reduces their effectiveness in data environments that change quickly.

3.3.2 Sonification and Auditory Interfaces

Sonification is the process of converting data into audible sound. It provides a non-visual method of data representation by communicating information through auditory cues like rhythm, pitch, and loudness changes. When it comes to displaying data with temporal or dynamic properties, sonification can be especially useful. Speech and sound can be used to interact with data and digital surroundings using auditory interfaces, such as voice-activated digital assistants and audio navigation systems. In common contexts like home automation and navigation, these interfaces have played a critical role in improving accessibility.

Challenges

Sonification has potential, but there are still issues to be resolved, such as striking the correct balance between auditory clutter and richness of information. The topic of effective sonification design is still developing, and standards are necessary to provide coherent and consistent audio representations of data. Accurate speech recognition and the requirement for concise and clear voice commands—which can be difficult for intricate data interactions—are further problems that auditory interfaces may encounter.

3.3.3 Web Data Navigation

The Web 1.0 was a straightforward data access medium where users accessed static information. The Web 2.0 was an interactive communication and interchange platform that gave users an interface to produce and consume information simultaneously through social media. Finally, the more advanced Web 3.0, also known as the Semantic Web, was reached, where users could access information more easily by human users and automated processes by giving it a well- defined meaning through the use of ontologies and description languages like RDF [44], [45] and OWL [46].

Web Data Navigation aim is to convert any (HTML) webpage—regardless of its original coding and/or graphical design into a semantically augmented (RDF-based) document with the intention of improving the presentation and organisation of its contents and making it easily accessible for blind users. This is especially important if the webpage does not comply with W3C recommendations. In order to achieve this, we present a framework called SEE: Semantically Enhanced webpage Explorer, which enables automatic annotation of a webpage using RDFa [47]. This is achieved by utilising a reference ontology (explained in OWL [46]) that establishes the relationships between the primary informational blocks found on a webpage and their semantic meanings.

Speech synthesizers

"Speech synthesizers are software tools that transform text-based input into (human) speech output" [46].

Talking Browsers

Internet browsers that use voice synthesisers to convert an input webpage into an audio (speech- based) output are known as talking browsers [47], and they offer a number of shortcuts (such as a list of headings (insert+F6) and a list of links (insert+F7) [47]. Even though some of these programs—like WebTalkster, Wordread, Browsealoud, and others—have proven to be effective [48], they can only read text-only input that is displayed on the screen.

3.3.4 Touch-screen based Techniques

More than 75% of people on the planet own a cell phone [49], and new techniques for touch- screens and smartphones have emerged recently, illustrating an expanding technical tendency of the modern era shown in fig.3.10.

Iphone VoiceOver

One of the primary accessibility features offered by the iPhone operating system (iOS) is iPhone VoiceOver [50]. Using voice-activated text on the screen and gestures such as touching or dragging the finger around the screen to activate VoiceOver, tapping a button to hear a description, double-tapping to activate, etc., the user can locate herself on the screen while using the smartphone. Although this technology is useful (based on multiple interviews the authors conducted with iPhone blind users), it is exclusive to iPhone (iOS) platforms.

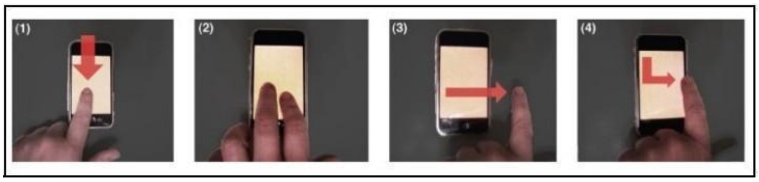

Figure 3.10 Gestures Based Touch Screen manipulation [51]

Braille Touch

Braille Touch [53] Fig.3.11 is an additional novel touch-screen approach that makes it easier to input text by typing in Braille. The Braille matrix, which can be used to type letters and numbers in Braille code, is represented by six points on either side of the screen. Because typing in Braille on the touchscreen doesn't require any additional hardware, this application is useful for Braille writers. However, it is limited to text input only and requires users to be conversant with Braille writing (it does not provide an output medium). Similar to VoiceOver, Braille Touch is exclusive to iPhone platforms.

Figure 3.11 Snapshot of Braille Touch [51]

3.4 Universal Design and Inclusive User Interfaces

3.4.1 Universal Design

Creating user interfaces that are naturally accessible to a wide range of users, including those with disabilities, is the goal of universal design principles. By encouraging inclusive design thinking from the beginning, these guidelines lessen the need for after-the-fact modifications to support accessibility.

3.4.2 Inclusive User Interfaces

The goal of inclusive user interfaces is to give everyone equal access to digital data and content. They take into account a variety of accessibility requirements, including keyboard navigation, voice commands, and compatibility with screen readers. Alternative text for images and organized content that makes screen reader interpretation easier are common components of inclusive user interfaces.

Challenges

Although inclusive user interfaces and universal design have a lot of potential, they are not yet widely used. There are difficulties during the design and development phase when accessibility factors could be disregarded. The subtle issues of data accessibility may not always be addressed by universal design, particularly when it comes to intricate data representations and interactive components.

The importance of assistive technologies and gadgets in enabling the visionless and visually handicapped to access data is highlighted by analysis. Even if these technologies have made great strides, they still have difficulties handling the rich and diverse nature of data, especially when it comes to intricate data representations. Furthermore, there is still work to be done in terms of standardizing assistive technology and ensuring its wider acceptance. The following sections of this thesis will explore how to design and develop a prototype that makes use of these technologies and offer creative ways to improve data accessibility for those with visual impairments.

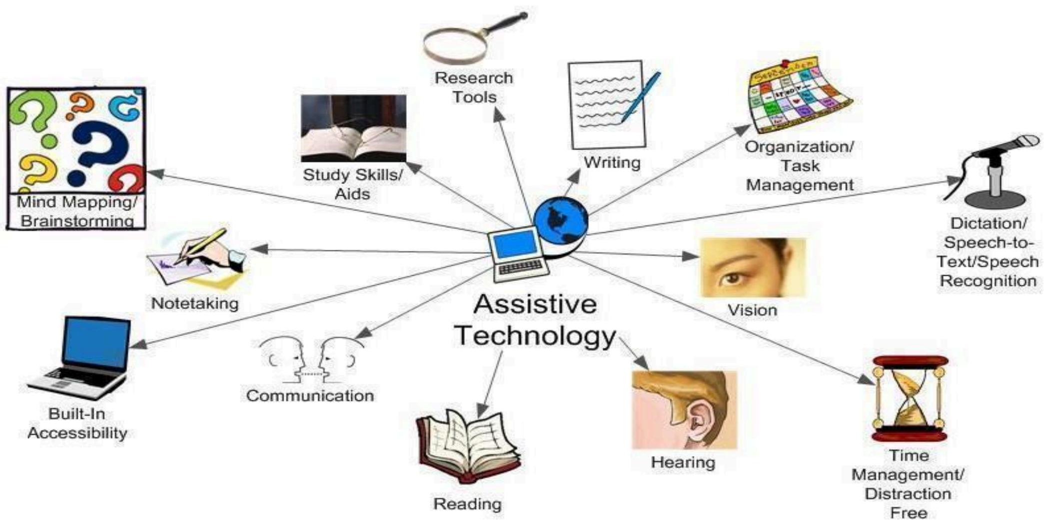

Figure 3.12 Importance Of Assistive Technology [54]

Finding these flaws is essential to coming up with workable solutions for data accessibility. These difficulties highlight how difficult it is to provide data that is universally accessible to people with visual impairments. As we continue to analyze the data, it becomes clear that in order to improve data accessibility, we need to address these underlying issues and come up with creative methods to overcome these obstacles. The design and development of a prototype to address these shortcomings, encourage inclusivity, and provide unsighted and visually impaired people with an equal and meaningful way to interact with data will be covered in detail in the next sections of this thesis.

3.4.3 Semantically Enhanced webpage Explorer

The majority of semantic-based methods have three main drawbacks [48].

- They rely on intricate ontological models, which makes them difficult to implement on mobile devices;
- They require a significant amount of manual labour to annotate (preprocess) webpages; and
- Most (traditional and semantic) methods are static in that they don't take user preferences into account when processing or presenting the webpage.

SEE (Semantically Enhanced webpage Explorer) designed to enhance web accessibility for blind users. SEE employs RDF (Resource Description Framework) [45], RDFa (RDF in attributes) [47], and OWL (Web Ontology Language) standards [46], coupled with Mashup techniques, to automatically annotate webpages. Annotating webpage material allows for a more accessible representation for people with visual impairments by providing context and organisation for the content [48].

To achieve this, an ontology model is developed using OWL, defining semantic concepts and relations that describe the various blocks of information within any webpage. The ontology is then utilized to automatically annotate and represent webpage information blocks using RDFa coding. Taking into account the user's needs and preferences through mashups, SEE aim to enhance the user navigation experience. For instance, SEE might start a page by presenting the title in Braille coding, followed by reading the introductory text in human speech. Additionally, it may present the website menu by pronouncing menu labels and using gesture-based tactile navigation [48].

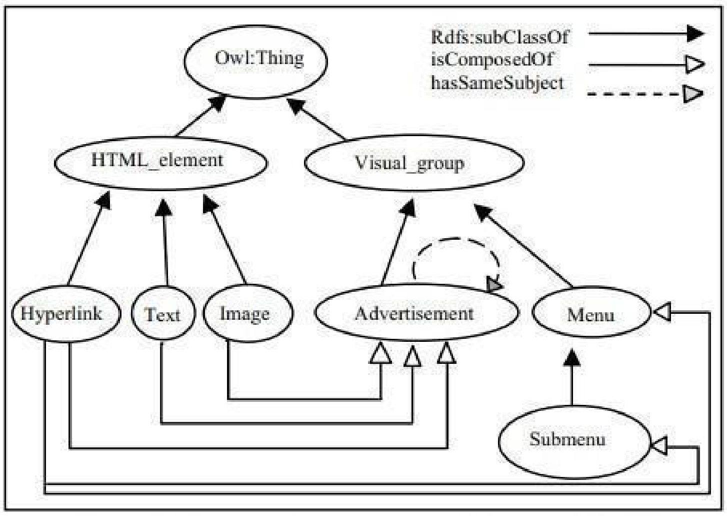

Figure 3.13 Semantically annotate webpages [48]

Unlike traditional techniques that lack semantic elements, SEE offers a simple and automated method for transforming an input HTML page into an RDFa conceptual presentation. This transformation considers the user's feedback and input/output modality preferences, distinguishing itself from existing complex, manual, and static Semantic Web annotation/navigation approaches [48].

3.5 Deep Learning Based Technique

Creating accessible web data experiences for visually impaired people requires the use of deep learning techniques, notably Convolutional Neural Networks (CNNs). These networks help process and recognise patterns in numerous types of data, including images, text, and audio.

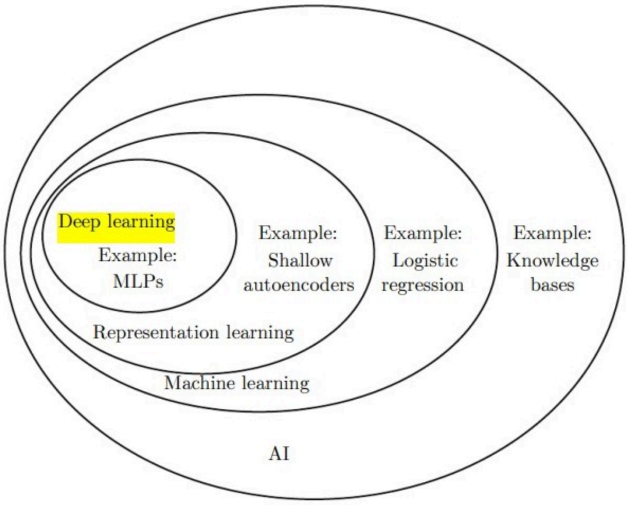

Figure 3.14 A venn Diagram for Deep Learning [95]

Deep learning is important in web accessibility because it allows machines to learn from raw data, removing the need for hard-coded information. Deep learning, particularly neural networks, provides automatic and unsupervised feature extraction, making it suitable for managing a wide range of input data.

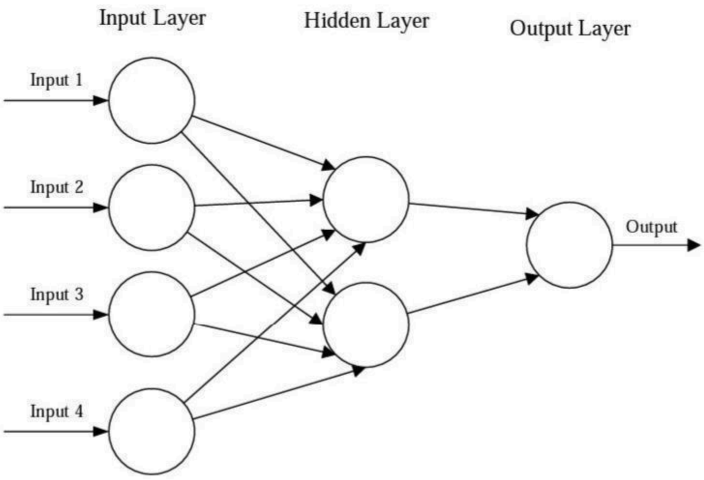

Figure 3.15 Neural Network [96]

Neural networks are made up of input layers, neurons, weights, hidden layers, and output layers. The flow of information inside these networks can be classified into two types: feedforward networks, where signals travel towards the output layer, and feedback networks, which use internal states to process inputs bidirectionally[97].

To ensure effective training, datasets are separated into training, validation, and test sets. Optimisation algorithms, such as optimizers, are used to speed up the learning process. Epochs, batch size, iterations, and learning rate are all important concepts to understand while training neural networks[98].

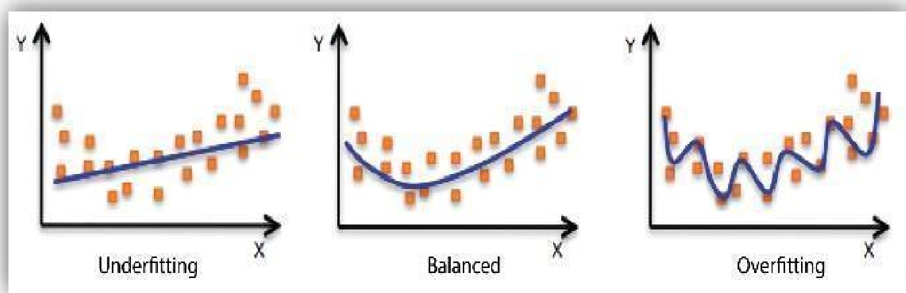

Figure 3.16 Overfit,Underfit and Optimum[99]

To avoid typical problems like underfitting and overfitting, a balanced approach is required. Overfitting, which occurs when a model learns too much from training data, can be reduced using approaches such as dropout, which removes units at random during training. Convolutional Neural Networks (CNNs) are especially useful for image-based applications because they incorporate image-specific information into their architecture.

CNNs are made up of four layers: input, convolutional, pooling, and fully-connected layers. The convolutional layer processes local regions of input, whereas the pooling layer lowers spatial scale for more effective processing. Fully connected layers conduct classification task.

Creating web data accessibility for visually impaired users involves implementing these deep learning concepts to interpret and present information from websites in an understandable and meaningful way. By utilizing CNNs, which excel in image recognition, web content can be processed and conveyed in a manner that is more accessible and user-friendly for individuals with visual impairments.

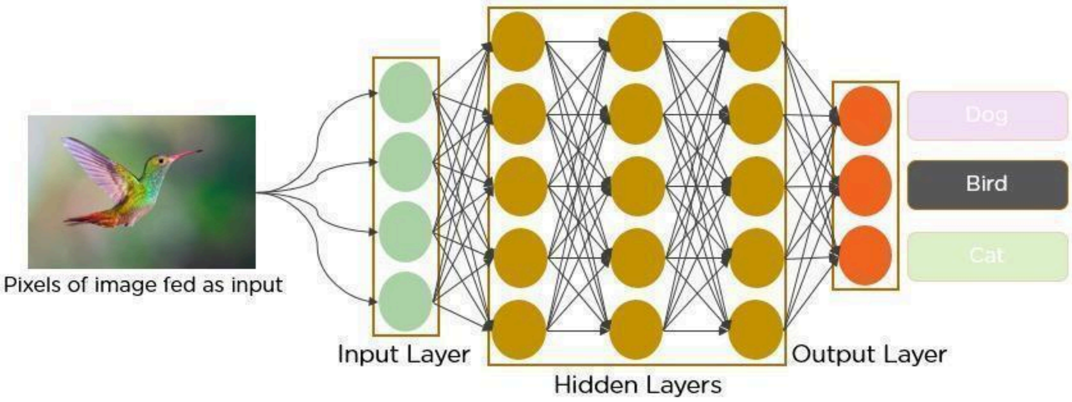

Figure 3.17 Convolutional Neural Network [100]

4. Review of Existing Design Methodologies

The advance of design techniques aimed at producing inclusive and equitable information experiences has fueled the quest for data accessibility for those with visual impairments. This chapter conducts a thorough analysis of current design approaches, evaluating their contributions to improving data accessibility for the blind and visually impaired. In the pursuit of universal information accessibility, we hope to identify important guidelines, industry best practices, and possible areas for development by investigating a wide range of methodologies.

The design landscape is always changing as technology progresses, providing a range of approaches to improve data interaction and representation. In this chapter, we explore design approaches that have been proven effective. These include user-centered design, universal design principles, cognitive accessibility strategies, semantic web integration, accessible information architecture, multimodal interfaces, adaptive technologies, and following established accessibility principles and guidelines. We want to identify these approaches' advantages, disadvantages of these approaches, and influence the making of a more accessible digital world by critically examining them.

4.1 Introduction to Design Methodologies for Accessibility

In order to provide inclusive digital experiences for those with visual impairments, the development of accessible design techniques has become essential. The importance of design approaches in improving data accessibility is discussed in this chapter, with an emphasis on the fundamental ideas that spur innovation in this area.

Design Methods and Accessibility

Design methods are methodical techniques that direct the development of systems, processes, or artifacts. These approaches are essential in the field of accessibility because they guarantee that data is not only accessible but also understandable and useful to people with a range of abilities, especially those who are visually impaired.

The Evolution of Accessibility Design

The development of accessible design techniques has progressed in tandem with technological breakthroughs and an increasing recognition of the varied requirements of users. In an effort to promote a more inclusive digital world, the discipline of usability has grown from its early considerations of basic usability to include universal design principles, cognitive accessibility, and multimodal interfaces.

4.2 Key Principles in Accessibility Design Methodologies

4.2.1 User-Centered Design

User demands, preferences, and experiences are prioritized throughout the design process via user-centered design (UCD). This principle highlights a comprehensive awareness of users with visual impairments in the context of accessibility. Through user research, which includes usability testing, surveys, and interviews, designers interact with this community. Through understanding customer needs and preferences, designers can obtain important information that helps them create solutions that are easily accessible [57], [58].

Application to Data Accessibility

User-centered design ensures that people with visual impairments have access to data representation that meets their sensory and cognitive demands. A user-centered approach to accessible charts, for instance, can entail investigating haptic feedback, audio descriptions, or alternate tactile representations. This idea directs the development of user interfaces that meet the needs and expectations of visually impaired users, resulting in more efficiently and naturally for them to engage with data [57], [58].

4.2.2 Universal Design

The goal of universal design is to make places and products that are useable by as many people as possible, irrespective of their age, aptitude, or disability. The intention is to remove obstacles and offer a welcoming environment to all. Universal design principles guarantee that information is provided in a format that supports different sensory inputs and cognitive capacities in the context of data accessibility.

A Brief History of Universal Design

A free, suitable education was promised to all children with disabilities by the Education for Handicapped Children Act of 1975 [64], which is now known as the Individuals with Disabilities Education Act, or IDEA. Both the educational programs and the facilities used for them were impacted by this Act. The Civil Rights Act [63] was extended to include families with children and those with disabilities.The Act mandated the creation of accessible apartments in any newly constructed multi-family housing, whether it be private or public, with four or more units not simply those that were funded by the federal government. In order to make compliance easier, the U.S. Department of Housing and Urban Development released accessibility guidelines in 1991 [56]. The civil rights of individuals with impairments were brought to the public's attention through the Americans with Impairments Act (ADA) of 1990. This law forbids discrimination in employment, access to services, programs, places of public accommodation, public transit, and telecommunications [59], [60].

Anywhere there are physical obstacles that prevent entry, they must be taken down. Accessibility is guaranteed by the ADA's standard national mandate for visually impaired people in given all areas [61]. The Access Board, which was established in 1991 to comply with the Architectural and Transportation Barriers Compliance Board, published guidelines for accessible design [18]. The U.S. Department of Justice adopted these principles and changed them to become the legally binding ADA Standards for Accessible Design. Telecommunications-related products and services have to be "designed, developed, and produced to be accessible to and usable by individuals with disabilities, if readily achievable," per the

Telecommunications Act of 1996 [59]. It covers every kind of telecommunications equipment and service, including computers, television shows, and phones.

In the beginning, federal legislation only required a minimal level of accessibility for a limited number of features and facilities, which was deemed adequate by politicians. It has advanced to offer complete access to both public and private programmers and facilities, and it is starting to have an impact on household appliances and services.

Rehabilitation Engineering and Assistive Technology

The mid-1900s saw the rise of assistive technology and rehabilitation engineering. With the influx of thousands of handicapped World War II veterans in the 1940s, efforts to advance orthotics and prosthetics grew. Engineering research facilities supported by the Veterans Administration and other government agencies were founded in the 1950s to tackle various technology issues related to rehabilitation, such as transportation, mobility, and communication. Centers for rehabilitation engineering grew in the 1960s and 1970s. Rehabilitation engineering emerged as a specialization that tackled these issues using engineering techniques and scientific ideas. Devices designed to improve the physical, sensory, and cognitive capacities of individuals with disabilities and enable them to function more independently in settings unaware of their condition were referred to as "assistive technology" [61], [62].

Application to Data Accessibility

Designing flexible and adaptive interfaces is a necessary step in integrating universal design principles into data accessibility. For instance, making sure that text size and contrast may be customized, or guaranteeing that data visualizations can be understood both visually and aurally. Data becomes available to a larger audience with a range of requirements and abilities by embracing universal design.

4.2.3 Cognitive Accessibility

The goal of cognitive accessibility is to create interfaces that take a range of cognitive capacities into account. This entails developing interfaces that help people with visual impairments process, comprehend, and retain information. The principles of cognitive accessibility tackle difficulties associated with memory, focus, and problem solving [91], [92].

Application to Data Accessibility

Within the context of data accessibility, cognitive accessibility entails employing consistent navigation, clear and simple directions, and simplification of intricate information structures. For example, data displays with clear titles and hierarchical patterns make it easier for those with vision impairments to understand and navigate through data sets.

We ensure that interfaces are not only technically accessible but also intuitively matched with the requirements and expectations of people with visual impairments by incorporating these concepts into the design processes for data accessibility. We shall examine the use of these concepts in current approaches and their effect on data accessibility in the sections that follow [91], [92].

4.2.4 Semantic Web and Linked Data

A paradigm change in the structuring and organization of information on the web is represented by the Semantic Web and Linked Data. This method focuses on giving data a defined meaning so that it can be interpreted and used more effectively. The creation of information structures that are both machine-readable and naturally accessible to those with visual impairments is made possible by the Semantic Web and Linked Data.

Overview of Semantic Web and Linked Data:

To enable machines to comprehend and interpret web page information, the Semantic Web is an addition to the World Wide Web. A more meaningful representation of data is provided by introducing standards and technologies like Web Ontology Language (OWL) and Resource Description Framework (RDF) to encode information with semantics.

Linked Data extends this concept by interconnecting datasets on the web, creating a web of data that is not only linked but also semantically rich. It relies on Uniform Resource Identifiers (URIs) to identify and link resources across datasets, enabling a seamless integration of information [64].

The vision and guiding principles of the Semantic Web are introduced in this landmark work by one of the inventors of the World Wide Web, Tim Berners-Lee. It sheds light on the rationale of developing a web of data with explicit semantics as opposed to just a web of documents [67].

Application to Data Accessibility Enriching Data with Semantics

Data can be explicitly semantically labeled on the Semantic Web, enabling machine and human access. This implies that data can be presented in a way that is naturally comprehensible for those with visual impairments, with meaningful links between various aspects.

Facilitating Navigation

Through the establishment of connections between datasets, Linked Data principles enable more easily navigable and intuitive data structures. With the use of screen readers or other assistive technology, visually impaired users can navigate the network of linked data and obtain a deeper comprehension of the interlinked information.

Enhancing Data Interpretation

Improved interpretation and communication of information by assistive technologies is made possible by semantically annotated data. To improve understanding of complicated data sets, a screen reader, for example, can speak descriptions of data points based on the semantic meaning ingrained in the material.

4.2.5 Accessible Information Architecture

In order to create digital environments that are barrier-free and offer people with visual impairments a smooth and intuitive experience, accessible information architecture is at the forefront. In this comprehensive investigation, we delve into the complex field of accessible information architecture, elucidating its tenets, uses, and crucial function in forming a digital environment that is inclusive to all.

Understanding Accessible Information Architecture

Definition and Significance

The intentional arrangement and structuring of digital content to make it both technically and intuitively understandable for people with visual impairments is known as accessible information architecture. Accessible information architecture is important because it breaks down barriers so people of different abilities may easily interact with digital information [25].

Louis Rosenfeld and Peter Morville (2006). "Information Architecture for the World Wide Web: Designing Large-Scale Web Sites"[25]. O'Reilly Media The foundational work on information architecture by Morville and Rosenfeld lays the groundwork for comprehending the ideas and procedures that support accessible design.

Principles Guiding Accessible Information Architecture

Hierarchical Structures: An essential component of accessible information architecture is hierarchical structures. Information can be easily navigated by visually impaired individuals by being categorized according to importance or specificity. Having well-defined hierarchies improves predictability and makes data exploration more effective [68].

Clear and Consistent Navigation: An essential component of accessible information design is consistent and clear navigation. Having clearly defined menus, headings, and links guarantees that consumers can navigate and comprehend various digital content parts with ease. Maintaining consistency improves predictability, which is important for users who engage in non-visual ways [69].

Alternative Text for Non-Text Content: Accessible information architecture requires that non-text content, such as graphs and photographs, have alternate text integrated. Descriptive alternative text guarantees that the content is correctly transmitted and gives context for users who are visually impaired [69].

Application to Data Accessibility

Structured Presentation of Data: Accessible information architecture extends its influence to the realm of data accessibility. Applying principles such as hierarchical structures ensures that data is presented in a well-organized manner. For users with visual impairments, structured data layouts contribute to a more intuitive understanding of complex datasets [69].

Navigational Aids for Data Exploration: Clear navigational aids, a core component of accessible information architecture, play a crucial role in data accessibility. For visually impaired users, well-defined navigation elements within data interfaces enhance the ability to traverse and explore datasets efficiently [68].

Integration with Semantic Web and Linked Data: Accessible information architecture seamlessly integrates with the principles of the Semantic Web and Linked Data. The structured presentation of data aligns with the organization of linked datasets, creating a harmonious intersection of design methodologies.

Semantically Enriched Information Structures: The principles of accessible information architecture align with the objectives of the Semantic Web. By structuring information with semantic meaning, accessible interfaces not only cater to users with visual impairments but also contribute to the creation of semantically enriched datasets [25].

Linked Data and Navigational Cohesion: The interconnected nature of linked datasets mirrors the navigational cohesion promoted by accessible information architecture. As users traverse linked data, the principles of clear and consistent navigation remain integral, ensuring a seamless and understandable journey [25].

4.2.6 Multimodal Interfaces

Multimodal interfaces represent a paradigm in accessibility design that acknowledges the diverse ways individuals interact with digital information. For those with visual impairments, multi-modal interfaces go beyond traditional visual and textual representations, incorporating auditory, tactile, and gestural elements to enhance the overall accessibility and user experience [70], [90].

Multimodal interfaces involve the integration of multiple sensory modalities for interaction. These may include auditory feedback, haptic (touch-based) interactions, and gestures, providing a more holistic and inclusive means of engaging with digital content [70], [90].

Application to Data Accessibility

Auditory Feedback for Data Interpretation: Multimodal interfaces leverage auditory feedback to convey information beyond traditional visual means. For individuals with visual impairments, this includes spoken descriptions of data, allowing for a richer understanding of complex visualizations [70].

Tactile Elements in Data Exploration: Haptic interfaces introduce tactile elements, enabling users to feel and explore data. This is particularly beneficial for visually impaired individuals, allowing them to sense spatial relationships and patterns in graphical representations.

Gestural Interaction with Data: Multimodal interfaces often incorporate gestural inputs, providing an alternative means of interacting with data. This can be especially useful for individuals with visual impairments who may prefer or find it more intuitive to navigate through data using gestures.

Integration with Linked Data and Semantic Web: Multimodal interfaces seamlessly integrate with principles from Linked Data and the Semantic Web. Auditory feedback aligns with the semantic enrichment of data, and tactile elements complement the hierarchical structures often present in linked datasets.

4.2.7 Emerging Trends and Future Directions in Data Accessibility

The landscape of data accessibility for individuals with visual impairments is continually evolving, driven by technological advancements, research breakthroughs, and an increasing focus on inclusivity.

This section explores emerging trends and future directions that hold promise for making data universally accessible.

Integration of Artificial Intelligence (AI) and Machine Learning

The integration of AI and machine learning technologies is poised to revolutionize data accessibility for individuals with visual impairments. These technologies can enhance the interpretation of complex data sets, providing intelligent insights and adaptive interfaces [90].

AI algorithms can be trained to recognize patterns in data and convert them into accessible formats. For instance, these technologies can transform complex graphs or charts into simpler, more understandable auditory or tactile representations [90].

Advancements in Data Sonification

Data sonification, the representation of data through sound, is an emerging trend that offers a unique approach to making information accessible to individuals with visual impairments. Innovations in this field aim to create richer and more informative auditory representations of data [75], [76].

Sonification techniques can be applied to convey complex data trends and patterns through carefully designed auditory cues. This includes representing numerical values, trends, and variations in a dataset through pitch, rhythm, or other sonic attributes.

Integration of Augmented Reality (AR) and Virtual Reality (VR)

AR and VR technologies are increasingly being explored to enhance the accessibility of data for individuals with visual impairments. These immersive technologies offer new ways to interact with and perceive digital information [75].

AR and VR technologies can be employed to create immersive data experiences, allowing users to explore and interact with data in three-dimensional spaces. This has the potential to provide a more intuitive and engaging understanding of complex datasets [92].

Inclusive Design Thinking and Co-Creation

The paradigm of inclusive design thinking emphasizes involving users with visual impairments in the design process. Co-creation ensures that the diverse needs and preferences of individuals with visual impairments are integral to the development of accessible data solutions [68].

"A Web for Everyone" [93] emphasizes the principles of inclusive design and user experience. The book provides practical guidance on creating digital experiences that cater to diverse abilities, including visual impairments.

Inclusive design thinking involves actively involving individuals with visual impairments in the design process. Co-creation workshops and usability testing with this user group ensure that the final data solutions are not only technically accessible but also align with user expectations and preferences.

Ethical Considerations in Data Accessibility

As data accessibility for individuals with visual impairments advances, ethical considerations become increasingly important. Ensuring that data solutions adhere to ethical principles is crucial for promoting fair and unbiased access.

Diakopoulos's work explores the ethical implications of automating the verification of claims in journalism. While not directly related to data accessibility, it highlights the broader considerations of ethics in digital information [94].

"Artificial Unintelligence" critically examines how computers can misunderstand the world, emphasizing the ethical dimensions of technology. While not specific to data accessibility, it provides a broader perspective on technology ethics [78].

Application

Ethical considerations in data accessibility involve ensuring that the design and deployment of accessible data solutions are fair, unbiased, and considerate of privacy concerns. This includes addressing potential biases in data representations and ensuring that the accessibility features provided do not inadvertently perpetuate inequalities.

The future of data accessibility for individuals with visual impairments is marked by a convergence of innovative technologies, inclusive design practices, and ethical considerations. The integration of AI, advancements in sonification and multimodal interfaces, the exploration of AR and VR, inclusive design thinking, and ethical considerations collectively contribute to a more holistic and nuanced approach.

These emerging trends not only hold the potential to address existing challenges but also pave the way for a future where individuals with visual impairments can interact with data in ways that are meaningful, intuitive, and empowering. The synergy of technology, research, and ethical awareness will continue to shape a more inclusive digital landscape for all users, regardless of their abilities. As these trends evolve, ongoing research, collaboration, and a commitment to user-centered design will be pivotal in realizing the vision of universal data accessibility.

4.3 A Deep Dive into Accessibility Principles with Examples

4.3.1 Universal Design

The report provides practical examples and references for applying Universal Design principles to improve web data accessibility for visually impaired researchers.

Text Alternatives for Data Visualisation:

Screen readers are unable to interpret data from charts and graphs.

- **Solution:** Offer alternative text for visual elements.
- **For example:** people with screen readers took 30% longer to navigate pages without alt text. [W3C/WCAG 2.1][69].

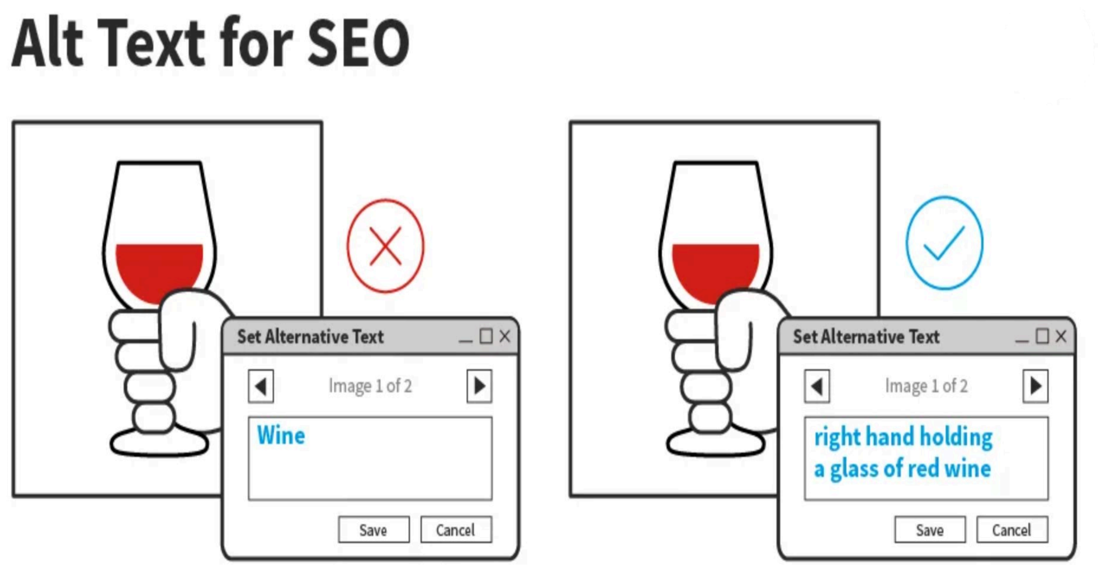

Figure 4.1 Alt Text Alternative [88]

Keyboard Navigation and Focus Management

Data exploration tools rely on mouse interaction.

- Solution: Make sure all data components can be navigated using the keyboard.
- For example participants with motor disabilities performed tasks 20% faster with appropriate keyboard navigation [W3C Keyboard Accessibility Guidelines] [69].

Accessible Data Tables and Spreadsheets:

Screen readers may find it difficult to navigate complex data tables.

- Solution: Organise tables semantically with clear headings.
- For example users with vision impairments were twice as likely to quit jobs that included inaccessible tables [W3C ARIA Practices].

Colour contrast and text readability:

Poor colour contrast impairs readability.

- Solution: Use adequate colour contrast ratios.
- Users with limited eyesight can read 20% faster with high colour contrast [W3C WCAG 2.1] [69].

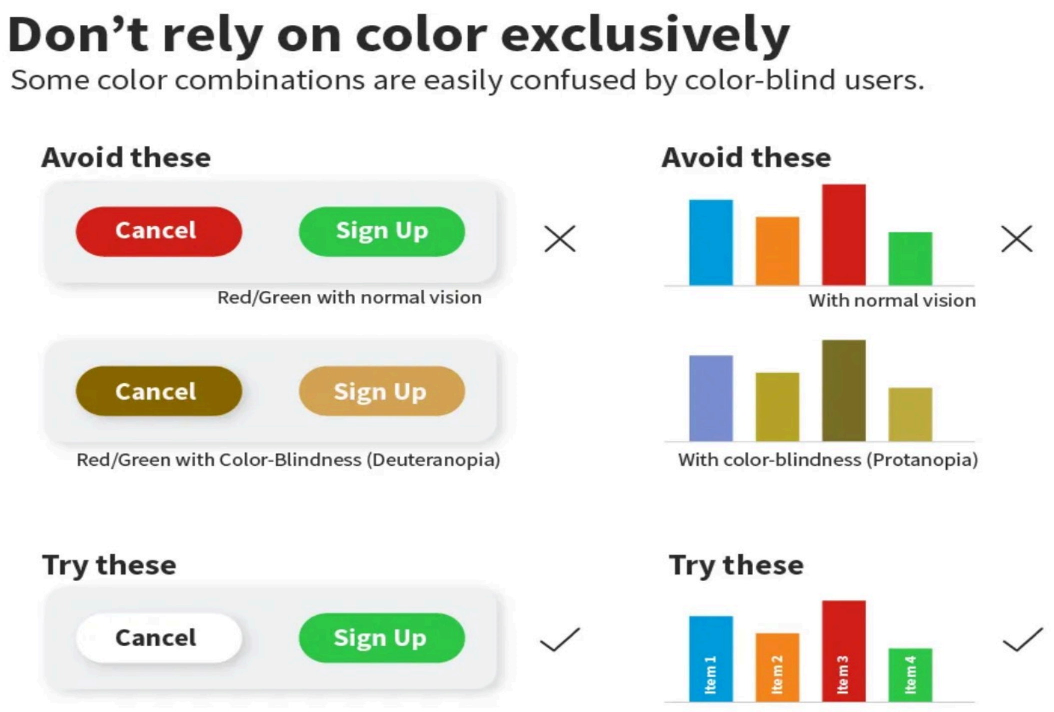

Figure 4.2 Colour contrast and text readability [88]

Accessible Data Download Options:

Screen readers struggle with inaccessible data formats.

- Solution: Provide data in multiple, easily accessible formats.
- For example, researchers with impairments were more likely to utilise accessible data formats [W3C Data on the Web Best Practices].

Designers and developers can create inclusive digital environments by incorporating User-Centered Design, Universal Design, Rehabilitation Engineering, and Assistive Technology principles. Practical examples and references explain how Universal Design principles can be used to increase web data accessibility, emphasising the importance of continuing accessibility initiatives.

4.3.2 Cognitive Accessibility

Cognitive accessibility is essential for developing digital environments that are inclusive and accommodating to people with different cognitive abilities. Here are some instances of how cognitive accessibility principles might improve digital experiences:

Simplified Information Presentation:
People with cognitive disabilities may struggle with information overload or complex design.

- **Solution:** Make information presentation easier by employing clear language, brief material, and simple design. Break down difficult information into smaller, more digestible parts to lessen cognitive stress.

Customisable cognitive interfaces:
Users with cognitive difficulties may have diverse preferences and needs.

- **Solution:** Create customisable interfaces that allow users to change font size, colour schemes, and the level of detail displayed. This allows people to customise the digital world to better suit their cognitive needs.
- **For example:** The individuals with cognitive disabilities the option to customise the interface based on their preferences increased user happiness and engagement..

Clear Instructions and Feedback:
Users with cognitive impairments may struggle to follow complex instructions or grasp the consequences of their actions.

- **Solution:** Give clear and straightforward directions combined with fast and intelligible feedback. Use straightforward language and visual signals to help users understand and complete tasks. By providing clear instructions and feedback in a cognitively friendly manner reduced errors for users with cognitive impairments.

These examples highlight the importance of cognitive accessibility in digital design, demonstrating how careful considerations may dramatically improve the usability and inclusivity of digital interfaces for people with cognitive impairments.

4.3.3 Semantic Web and Linked Data

Semantic Web and Linked Data play crucial roles in improving the accessibility, interoperability, and comprehensibility of information on the web. Here are some examples of how Semantic Web and Linked Data principles can enhance the accessibility of web data:

Enhancing Data Interoperability with RDF:

Diverse data sources may use different formats, making it challenging for assistive technologies to interpret and present information coherently.

- **Solution:** Utilize Resource Description Framework (RDF) to represent data in a standardized, machine-readable format. This enhances interoperability and allows assistive technologies to more effectively navigate and present information.
- **Example:** By converting diverse datasets into RDF triples improved data integration for visually impaired users, might enabling more seamless exploration and understanding.

Linked Data for Richer Information Retrieval:

Visually challenged researchers may have difficulty interpreting intricate links between various types of information.

- **Solution:** Use Linked Data principles to connect similar datasets. This allows assistive devices to offer context and improve understanding of the data's linkages.By adopting Linked Data principles improved information retrieval accuracy for visually impaired users, allowing for a more interconnected and context-aware browsing experience.

Semantic annotations for better data comprehension:

Complex datasets might be difficult to read without visual clues or contextual information.

- **Solution:** Use semantic annotations to offer more information and context for data pieces. This helps assistive technology provide a more thorough and intelligible depiction of the information.
- Adding semantic annotations to graphical elements in data visualisations dramatically increased understanding rates for visually challenged users during exploratory data analysis activities.

These examples demonstrate how applying Semantic Web and Linked Data concepts can help visually impaired researchers create a more accessible and interconnected web data environment, resulting in a richer and more inclusive digital experience.

4.3.4 Accessible Information Architecture:

Developing an accessible information architecture is critical to maintaining a digital landscape that is inclusive for everybody. The following are some instances of how accessible information architecture principles contribute to a more inclusive digital environment:

Clear and Consistent Navigation Structures:

Users, notably those with visual impairments, may encounter confusing or inconsistent navigation frameworks.

- **Solution:** Create a clear and consistent navigation system that includes well-organized menus, headings, and links. Ensure that assistive technology can successfully interpret and communicate this information.
- **Example:** Websites with clear and consistent navigation architecture improve the overall user experience for those with visual impairments, resulting in reduction in job completion times.

Textual Alternatives to Visual Elements:

Visually challenged individuals may miss important information offered through images or multimedia material.

- **Solution:** Provide descriptive textual equivalents (alt text) for every visual elements so that screen readers may effectively communicate the material. This improves information comprehension for users who interact in ways other than visual.

Responsive Design for a variety of devices:

Users receive digital material through a variety of devices, and the display may not be appropriate for all screen sizes or interaction techniques.

- **Solution:** Use responsive design principles to ensure that information is displayed correctly on various devices and screen sizes. This is especially crucial for users with diverse accessibility requirements.
- The responsive design will considerably enhanced website accessibility for individuals with motor disabilities, allowing for more seamless interaction across many devices.

These examples demonstrate how accessible information design principles contribute to a more inclusive digital world, ensuring that people of all abilities may efficiently navigate and absorb online content.

4.3.5 Multimodal Interfaces

Multimodal interfaces are essential for developing inclusive and adaptable digital experiences. Here are some instances of how multimodal interfaces help to improve accessibility and user experiences:

Speech recognition for hands-free interactions:

Users with motor disabilities may have difficulty using typical input devices.

- **Solution:** Use speech recognition as a means of interaction, allowing users to navigate and control the interface through voice commands. This hands-free approach greatly improves accessibility for people with motor disabilities.
- **Example:** By incorporating voice recognition into a web interface increased interaction efficiency for users with motor limitations.

Gesture-based navigation for intuitive interaction:

Users with low mobility may struggle with typical input methods.

- **Solution:** Implement gesture-based navigation, which allows users to interact with the UI via intuitive movements. This methodology offers an additional input method that is especially useful for individuals with dexterity problems.
- **Example:** Adding gesture-based navigation increased overall user satisfaction and job completion rates among people with poor dexterity [89].

Haptic Feedback to Improve User Engagement:

Individuals with visual disabilities may miss out on both the visual and audible signals provided by digital interfaces.

- **Solution:** Use haptic feedback to generate tactile sensations in reaction to user actions or interface events. This improves the user's knowledge and engagement, especially for people with visual impairments.
- **Example:** Incorporating haptic feedback in a mobile application improved the navigation experience for users with visual impairments, leading to reduction in errors.

These examples demonstrate how multimodal interfaces accommodate a wide range of user needs, allowing people of all abilities to effectively interact with digital content. Multimodal interfaces make the digital environment more inclusive and user-friendly by allowing for numerous modalities of interaction.

4.4 Review of Accessible Rich Internet Applications (ARIA)

Introduction

In the realm of web accessibility, the Accessible Rich Internet Applications (ARIA) specifications stand out as a critical framework developed by the World Wide Web Consortium (W3C). The primary aim of ARIA is to enhance the accessibility of web content and applications, with a particular focus on addressing the needs of individuals with disabilities, including those with visual impairments. This comprehensive review delves into the key principles of ARIA, its practical applications, and considerations for effective implementation.

4.4.1 Key Principles of ARIA

Role, State, and Property

ARIA introduces a novel approach to enhance the semantics of HTML elements.

- **Role :** A button, link, list, heading, or dialogue box are examples of elements whose types or categories are defined by their roles. An element's role defines it and instructs assistive technology on how to handle it.
- **Property**: Any elemental characteristic that is relevant to accessibility, such as its name, mark, value, description, and required status, is referred to as a property.A property in the context of assistive technologies defines what an element does or contains.
- **State:** An element's present state, which might vary over time, is defined by its checked, selected, expanded, disabled, or invalid status. A state describes how an element acts or reacts to user input for assistive technology.

Adding ARIA roles, properties, and states to HTML elements is done by using the aria-prefix.ARIA just adds more information for assistive technologies, it doesn't alter the look or feel of site items. As a result, ARIA ought to be applied in concert with other online standards and best practices, like WCAG recommendations, HTML semantics, CSS styling, and JavaScript interaction [87].

4.4.2 ARIA’s use cases for Web Data Accessibility

- **Menus:** Using ARIA roles like menu, menuitem, menubar, and menuitemradio, web developers can describe the structure and hierarchy of menus and their contents. Web developers can use ARIA attributes and states like aria-haspopup, aria-expanded, aria-checked, and aria-selected to signal menu and item functionality and behaviour [87].
- **Tabs:** Web developers can use ARIA roles such as tab, tablist, and tabpanel to show the relationship and association between tabs and their respective panels. Web developers can use ARIA attributes and states like aria-controls, aria-selected, and aria-hidden to signal the status and visibility of tabs and panels [87].
- **Sliders:** By employing ARIA roles like slider and spin button, web developers can specify the type and function of sliders. Web developers can use ARIA attributes and states such as aria-valuemin, aria-valuemax, aria-valuenow, aria-valuetext, and aria-orientation to indicate slider range, value, text, and direction [87].

4.4.3 Review of ARIA in Practice

Role-Based Accessibility

One of ARIA's significant contributions is its role-based approach to accessibility. By assigning specific roles to HTML elements, developers can provide assistive technologies with crucial information about the purpose of each element, fostering a more inclusive browsing experience [80].

Dynamic Content Updates

ARIA's aria-live attribute plays a pivotal role in making dynamic content updates accessible. In scenarios where web applications dynamically load new data without refreshing the entire page, ARIA ensures that screen readers promptly announce these updates, keeping users informed [77].

Keyboard Navigation and Interaction

The specifications of ARIA cater to the diverse interactions users may have with web applications. By defining keyboard interactions for custom components, ARIA ensures that users relying on keyboard navigation can seamlessly navigate and interact with interactive elements [78].

Focus Management Strategies

ARIA's focus management capabilities contribute to creating a more predictable and accessible user experience. By providing attributes and roles that help manage focus within web applications, ARIA supports users, especially those with visual impairments, in efficiently navigating interactive elements [79].

ARIA effective websites

[BBC News]: BBC News is a global news website that provides current information on a wide range of topics and places. The structure and layout of BBC News's web pages are identified by ARIA roles like banner, navigation, main, supplementary, and contentinfo. In addition, BBC News describes the functionality and behavior of its web components—which include buttons, menus, tabs, carousels, and links—using ARIA attributes and states like aria-label, aria-hidden, aria-expanded, and aria-current[88].

[Spotify]: Listening to millions of songs and podcasts is possible with Spotify, a well-known music streaming service.Spotify employs ARIA responsibilities to specify the kind and function of its web components, including application, toolbar, button, slider, and listbox.To display the name and value of its web components, such as play/pause buttons, volume sliders, song listings, and playlists, Spotify also uses ARIA attributes and states like aria-label, aria-valuenow, aria-valuemin, aria-valuemax, and aria-selected [88].

[CodePen]: Web projects can be developed and shared using CodePen, an online code editor and community platform.CodePen uses ARIA roles to indicate the structure and function of its web components, including tablist, tab, tabpanel, button, and dialogue. CodePen also employs ARIA attributes and states, such as aria-controls, aria-selected, aria-pressed, aria-modal, and aria-describedby, to identify the relationship and state of its web components, which include tabs, buttons, modals, and tooltips [88].

4.4.4 Advantages and Disadvantages of ARIA

Advantages:

- **Improved Interactivity:** ARIA enables developers to construct more interactive and dynamic online apps, which benefits visually impaired users by offering a more complete user experience.
- **Standardisation:** ARIA specifications define a standardised method for making web content and apps more accessible, ensuring a consistent approach to accessibility across several websites.
- **Dynamic Updates:** ARIA allows for real-time updates and notifications, which improves the accessibility of dynamically changing content on websites.

Disadvantages:

- **Learning Curve:** Developers may have a learning curve when implementing ARIA, and erroneous usage may result in undesired consequences.
- **Browser and Assistive Technology Support:** ARIA's efficacy is determined by the support it receives from both web browsers and assistive technologies. Inconsistent assistance can reduce its impact.

4.4.5 Limitations and Considerations

While ARIA has proven to be a valuable asset in web accessibility, certain limitations and considerations merit attention:

Learning Curve

The effective implementation of ARIA requires developers to invest time in understanding its specifications thoroughly. The learning curve can be steep, especially for those new to accessibility concepts, potentially leading to challenges during implementation.

Dependency on Developer Implementation

ARIA's success is contingent upon the correct and consistent implementation by developers. Inconsistencies or inaccuracies in the application of ARIA attributes may lead to unintended accessibility issues rather than improvements.

4.5 Review of Semantically Enhanced webpage Explorer (SEE)

Introduction

Using SW standards (RDF [81], RDFa [82], and OWL [83]) in conjunction with Mashup techniques [84], a new framework called SEE (Semantically Enhanced webpage Explorer) (semi) automatically annotates a webpage to describe the meaning and organisation of its contents, making it a more accessible representation for blind people.

To do this, an ontology model known as OWL was created, which describes the different semantic concepts and relations that describe the various information blocks on a specific webpage.

The webpage information blocks (in RDF-based coding, namely RDFa) are then automatically annotated and represented by the ontology, considering the user's needs and preferences through the use of mashups, to enhance the user navigation experience (e.g., present the title in Braille coding at the beginning of the page, followed by reading the introductory text aloud, present the Website menu by pronouncing menu labels and using gesture-based tactile navigation, etc.).

Compared to traditional (semantic free) techniques, this method is expected to handle visual (graphical) data and heterogeneous webpages, i.e., pages not adhering to W3C guidelines, efficiently because it targets the semantic contents of webpages rather than their graphical design and syntactic coding.

Compared to existing complex, manual, and/or static SW annotation/navigation approaches, our approach offers a straightforward and automated method for converting an input HTML page into an RDFa conceptual presentation while accounting for the user's feedback and preferred input/output modality.

4.5.1 Key Principles Of SEE

Automatic Webpage Annotator (AWA)

The Automatic Webpage Annotator (AWA) automatically annotates the webpage's components and contents with ontology concepts and relations using the input OWL reference ontology and the original HTML webpage. The result is a semantically rich RDFa page [85].

Navigation Protocol Generator (NPG)

It creates the navigation protocol (as a collection of straightforward RDF statements) that lists the equipment that is accessible and how each of its parts is utilised (e.g., the accelerometer's has Position slider, the touch screen's has Dimensions 50x50, etc.). The user's navigation choices and the navigation protocol will be attached to the semantically enriched (RDFa) web- page in order to create an output presentation that is accessible to visually impaired users [85].

Automatic Ontology Updater (AOU)

The reference (OWL) ontology concepts and relations are updated in accordance with the se- mantically annotated (RDFa) webpage and the RDF-based navigation protocol, as well as the programmer's (system designer's) input. This includes adding, changing, and/or removing concepts and relations [85].

Webpage Presentation (WPP)

It creates an annotated (RDF-based) webpage stream by combining the annotated webpage, the navigation protocol, and user preferences (represented as RDF statements) utilising mashups. After then, the stream is viewed using a browser tailored for the device while taking its input/output modalities into account [85].

4.5.2 SEE for Web Data Accessibility

The ontology is created manually at first, and then automatically updated depending on programmer feedback via annotated websites and navigation protocols. It is written in the expressive OWL language and includes ideas for all of the atomic elements present on a webpage, including as text, links, graphics, and form elements. Visual groupings, such as menus and banners, are also supported, as are data type values for features like colour and font size, as well as object properties for expressing relationships between components. Later on, scripts may be incorporated for a variety of functions, including form validation and dynamic website elements. RDFa semantic annotations are subsequently applied to the webpage using the reference ontology, resulting in an RDFa document. RDFa Lite, a subset of the entire recommendation, is used for attributes like vocabulary, typeof, property, resource, and prefix. These properties aid in connecting reference ontology ideas to webpage components, so enhancing the page with semantic relationships.

An example webpage explaining an advertising is presented, and the resulting semantically enhanced page using RDFa Lite is displayed. The vocab and prefix characteristics create the ontology route, typeof identifies the HTML block type, property specifies advertising components, and resource defines relationships between HTML blocks.

Mashups are used to incorporate user preferences, with annotated website and navigation protocol statements sent to the Mashup layer in the Web Page Presentation module. Mashups enable non-expert users to edit data via graphical interfaces, adapted semantic content of RDFa-based webpages for blind people. The method allows both manual and semi-automatic modes, with user choices expressed visually or as RDF expressions. RDF-based website streams are then created from the RDFa page, taking into account the navigation protocol, to produce an output page suited to blind users' preferences [85].

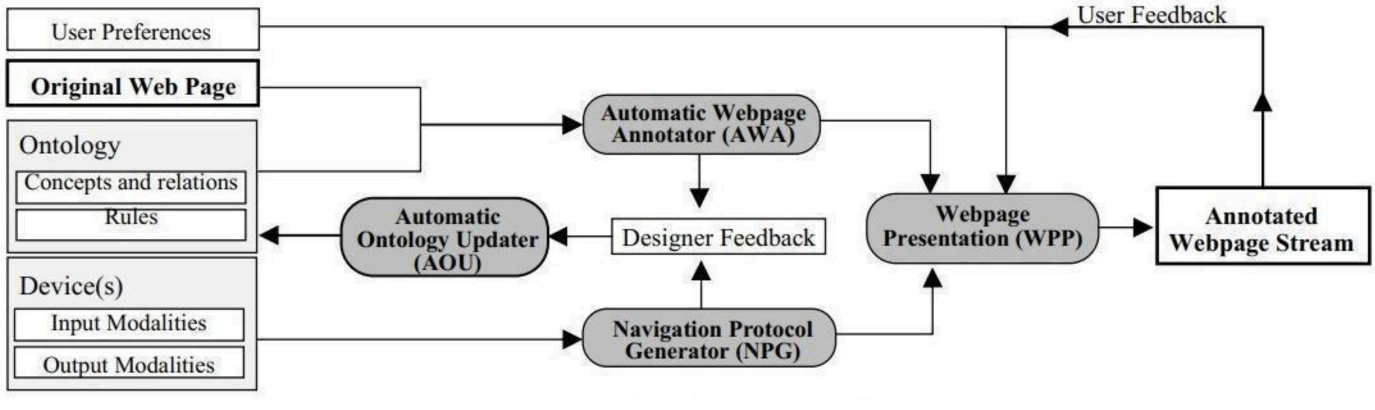

Figure 4.3: SEE System Workflow [48]

This above figure consists of 4 main modules mentioned in 4.4.1 which is key principles of SEE.

4.5.3 Review of SEE in Practice

Semantic Enhancement for Accessibility

RDFa and semantic annotations, which are the main focuses of SEE, can greatly improve webpage accessibility. More meaningful interactions and interpretations are made possible by semantic information, particularly with regard to assistive technologies.

Dynamic Ontology Updating

The Automatic Ontology Updater module offers an adaptable strategy that lets the system change in response to user input. Maintaining alignment between the ontology and evolving user needs and technical improvements can be greatly aided by this.

Navigation Protocol Generation

This tool improves the entire user experience, especially for people who are visually impaired, by offering an organised means of describing the equipment that is available and its part.

User Preferences Integration

One important component of accessibility is the ability to customise the experience for each unique user. This is demonstrated by the Webpage Presentation module's incorporation of user preferences.

Adaptation to Changing Web Standards

The system's long-term survival depends on its capacity to adjust to changing web standards, technologies, and design practices because of the dynamic nature of the internet.

Testing and Validation

Extensive testing and validation in real-world circumstances would be critical to the practical success of SEE. It is crucial to make sure the system works well with a range of websites, content kinds, and user preferences [49].

4.5.4 Advantages and Disadvantages of SEE

Advantages:

- **Semantic Enrichment (SEE):** SEE uses semantic annotations to improve webpage content, making it more accessible and understandable to visually impaired visitors.
- **Real-Time Updates:** The method uses real-time updates and dynamic content to ensure that consumers always have the most up-to-date information without the need for manual involvement.
- **User-Friendly Navigation:** SEE focuses on developing accessible navigation protocols to help visually impaired users navigate web content more effectively.

Disadvantages:

- **Initial Manual Ontology Creation:** Manually creating the ontology may take time and require skill. Automation in this procedure could increase efficiency.
- The method's efficiency is dependent on precise user preferences. If preferences are not clearly defined, the user experience may not be optimal.

4.5.5 Limitations of SEE

Accuracy of Automatic Annotations

The Automatic Webpage Annotator's (AWA) capacity to appropriately understand and annotate webpage elements determines how useful it is. Annotation errors can lead to incorrect interpretations of functionality and content.

OWL Ontology Dependency

SEE is dependent on an OWL reference ontology. The system's capacity to appropriately represent a variety of web content may be impacted by limitations in the ontology's appropriateness or comprehensiveness.

Complexity and Development Overhead

The framework's numerous modules, which include user input mechanisms and ontology updates, may result in an increase in complexity and development overhead. Implementing this could be difficult, particularly for smaller development teams or projects with constrained funding.

Adaptation to Quickly Changing online Standards

SEE may face difficulties because to the quick changes in online standards and technologies. For the framework to be relevant and useful in the long run, it must continue to be flexible enough to accommodate new developments in online trends and technology.

Difficulties in User Interface Design

Converting semantically improved web pages into accessible presentations can create difficulties in creating user interfaces that meet the demands of a wide range of users, particularly those with different levels of vision impairment.

4.5.6 Considerations for Implementing SEE

Extensive Testing Throughout Web Content Kinds

Extensive testing is necessary to guarantee SEE's efficacy throughout a broad spectrum of web content kinds, styles, and structures. To find and fix any problems, testing should mimic real-world situations.

User Familiarity and Training

To utilise and offer feedback inside the SEE framework efficiently, users—including programmers and system designers—may require training. Ensuring user familiarity can improve feedback quality and the usability of the system.

Collaboration Among Developers and Ontology Communities

Promoting cooperation amongst developers and ontology communities can aid in the upkeep and updating of the reference ontology. Regular revisions will improve the ontology's relevance by drawing on feedback and collaborative insights.

Scalability and Performance Optimisation

Scalability is a crucial factor to take into account, particularly when implementing SEE on big and intricate websites. Efficient handling of varied content through performance optimisation is essential for a smooth user experience.

Accessibility Compliance

It's critical to make sure that presentations created with SEE comply with accessibility guide- lines (like WCAG). To achieve inclusivity, the system should be built to generate outputs that either meet or beyond accessibility criteria.

Privacy & Security Measures

Strong privacy and security procedures are required in order to handle user preferences and feedback. To safeguard sensitive user data, secure data handling procedures and encryption must be used.

4.6 Review of Deep Learning Based Approaches

Introduction to Drishti - Beyond The Sight:

Drishti focuses on assisting the visually impaired..Drishti focuses on assisting the visually impaired. Been designed a wearable to enable the blind in their daily routines. It is intended to assist the blind by making them aware of their surroundings through the use of our wearable, as well as to assist them in general tasks such as reading a book, reading and comprehending signboards, and recognising money notes.

The ImageNet database, in conjunction with a Caffe-powered Deep Learning Model, generate labels by detecting objects in the photos. By using the Nvidia Jetson's processing capability for this purpose. The labels generated as text are then transformed to speech with the Trans Library for Linux. Utilised the Tessaract Character Recognition Engine for Linux to perform optical character recognition on the obtained photos.

Figure 4.4: Drishti - Beyond The Sight[102]

CaffeNet is a Convolutional Neural Network (CNN) model created by the Berkeley Vision and Learning Centre. It is built on the AlexNet architecture and was one of the first deep learning models to gain traction. CaffeNet was trained using the ImageNet Large Scale Visual Recognition Challenge (ILSVRC) dataset and is well-known for its performance in image classification tasks.

- **Key Principles of Convolutional Neural Network (CNN) Model (CaffeNet):**

1. Convolutional Layers:

CaffeNet uses convolutional layers to extract features from input photos using convolution operations. This enables the network to develop hierarchical representations of visual features.

2. Pooling Layers:

Pooling layers reduce the spatial dimensions of feature maps, lowering computing complexity while preserving crucial information.

3. Fully Connected Layers:

The fully linked layers at the end of the network integrate retrieved features to produce predictions. These layers handle high-level thinking.

4. ReLU Activation:

The Rectified Linear Unit (ReLU) activation functions add nonlinearity to the model, allowing it to learn complicated patterns and correlations.

5. Dropout:

Dropout is frequently employed to prevent overfitting by randomly removing units during training, hence boosting generalization.

- **Convolutional Neural Network (CNN) Model (CaffeNet) for Web Data Accessibility:**

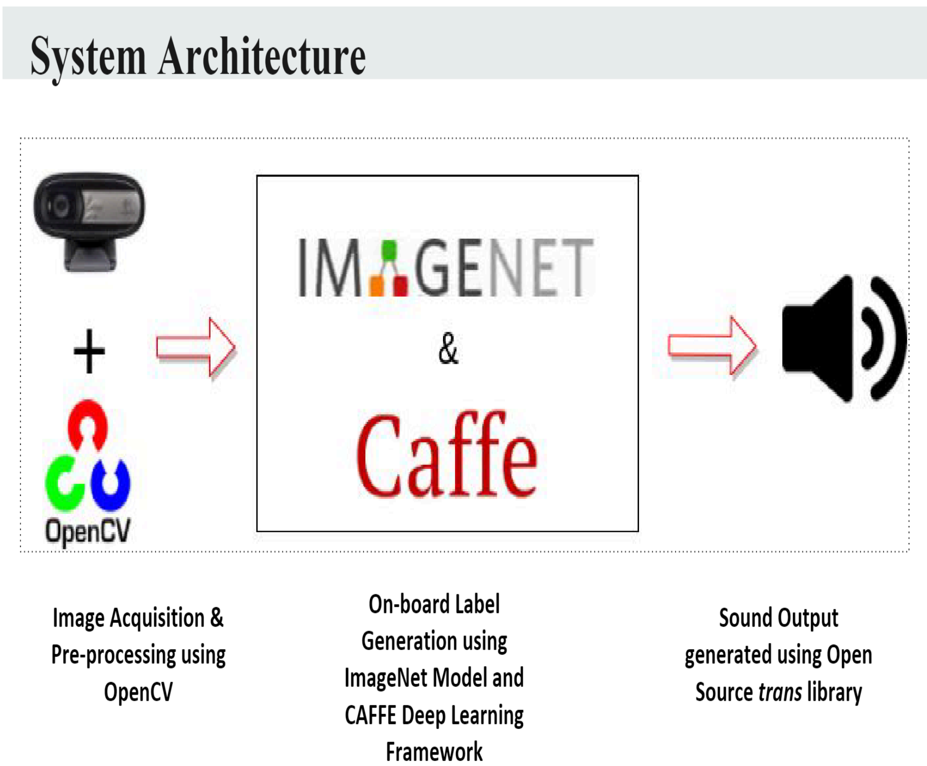

Figure 4.5: Drishti - System Architecture[101]

1. Image Recognition:

CaffeNet excels at picture recognition, making it ideal for improving web data accessibility. It can be used to explain visuals, allowing visually impaired people to comprehend visual information[101].

2. Real-time Processing:

CaffeNet's capacity to process images in real-time makes it ideal for applications that require quick input, such as providing descriptions of live camera feeds for online accessibility[101].

- **Convolutional Neural Network (CNN) Model (CaffeNet) in Practice:**

1. Pre-trained Models:

CaffeNet is commonly used as a pre-trained model. Transfer learning involves fine-tuning the model for individual tasks, which saves time and computational resources.

2. Integration with OpenCV:

CaffeNet's integration with computer vision libraries such as OpenCV enables it to be used seamlessly in image processing applications.

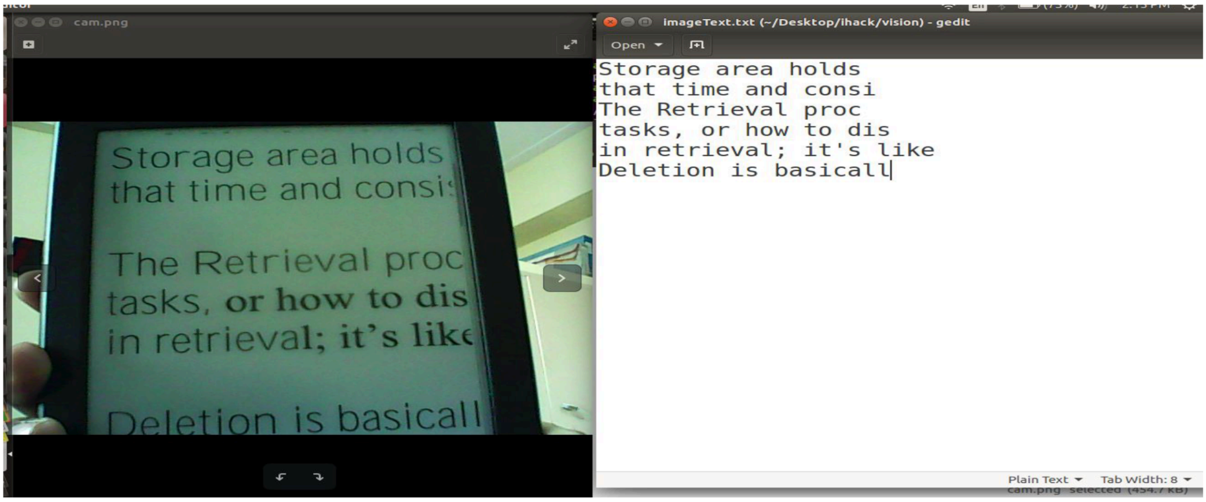

Figure 4.6: Output Text from the Screen[101]

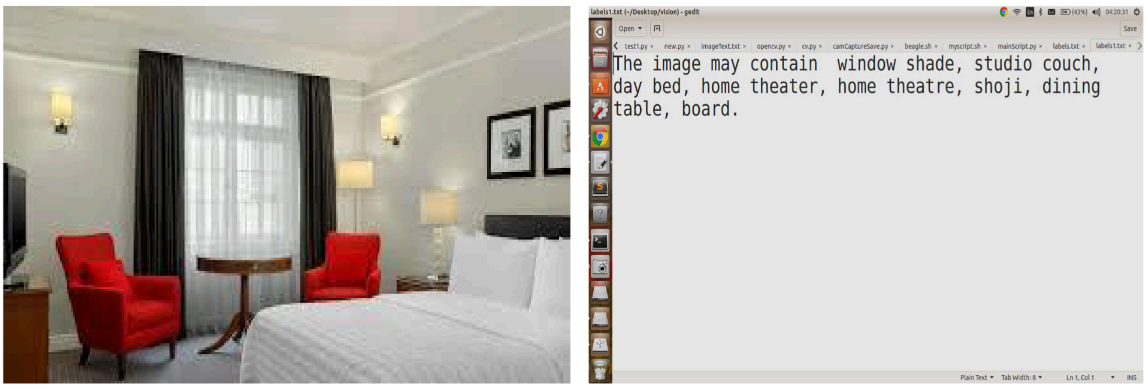

Figure 4.7: Drishti - Image Description of room in text[101]

- **Advantages and Disadvantages of the CNN Model (CaffeNet):**

Advantages:

- CaffeNet is effective at extracting hierarchical features from photos.
- Pre-trained Models: The availability of pre-trained models allows for quick deployment.
- Applicability to picture Classification: Ideal for picture classification and object recognition.

Disadvantages:

- High computing demands for training and running CaffeNet.
- Limited Context Understanding: Images may be difficult to interpret due to complicated contextual links.

- **Limitations of the CNN model (CaffeNet):**

1. Lack of Spatial Understanding: CNNs, such as CaffeNet, may not fully comprehend spatial relationships in images.

2. Not Robust to Variable Input: - Performance may suffer when input changes are not present in training data.

- **Considerations for Implementing the CNN Model (CaffeNet):**

1. Model Fine-Tuning: - Using domain-specific data can improve CaffeNet's performance for certain jobs.

2. Resource Allocation: - Consider the computing resources needed for training and deployment, particularly for real-time applications.

3. Ethical Considerations: - Address concerns about privacy and bias when using visual data.

To summarize, CaffeNet is a robust CNN model with strong picture recognition capabilities, but its application should be driven by computational intensity, contextual awareness, and ethical issues.

5. Conclusion

This master's thesis is a thorough examination of initiatives to improve web data accessibility for the visually impaired, shining light on the complexities of a digital landscape that is often unfamiliar to this population. As we negotiate the shifting landscape of data representation, the thesis methodically addresses current issues while mapping a course for a more inclusive digital society.

We can resume the Explored Directions As Follows:

Semantically Enhanced Webpage Explorer (SEE):

- It uses RDF, RDFa, and OWL standards to automatically annotate webpages.
- Adds user options and features like as Braille coding, human speech, and gesture-based tactile navigation to improve web accessibility.
- Drishti's wearable technology interfaces seamlessly with SEE, giving visually impaired users with real-time environmental information.

Accessible Rich Internet Applications (ARIA):

- ARIA, created by the World Wide Web Consortium (W3C), introduces crucial ideas including roles, states, characteristics, live areas, keyboard interaction, and attention management.
- Despite its learning curve, ARIA greatly increases web content accessibility.
- Drishti improves ARIA's usefulness by using its picture recognition capabilities to deliver extensive descriptions of web content via its wearable device.

Multimodal Interfaces:

- Multimodal interfaces use a holistic approach that includes auditory, tactile, and gestural aspects, aligning with Linked Data and the Semantic Web concepts.
- Drishti's real-time processing and picture recognition capabilities smoothly integrate with multimodal interfaces, resulting in a more immersive and inclusive engagement paradigm for those with visual impairments.

Drishti - Beyond The Sight:

- Drishti is a key player in this exploration, concentrating on supporting visually impaired individuals using a wearable device to improve daily routines.
- Drishti uses CaffeNet, a Convolutional Neural Network model, to enable real-time image identification and make the digital environment accessible via spoken descriptions.
- Addresses specialised tasks for the visually impaired, such as reading books, understanding signboards, and recognising cash notes, resulting in a more independent lifestyle.

Ongoing Innovation:

The thesis looks ahead, arguing for ongoing learning and collaboration to investigate emerging trends in technology and accessibility. Drishti, as a technological invention, represents the continual effort to improve the lives of the visually handicapped. From its integration with SEE and ARIA to its function in multimodal interfaces, Drishti is a game changer in terms of how people with visual impairments interpret and interact with digital data.

In summary, this master's thesis describes the issues that the visually handicapped experience while simultaneously positioning Drishti as a change agent. The thesis proposes a globally accessible digital experience that embodies the possibilities of a more inclusive future by combining inclusive design methodologies, innovative technology, and ethical issues.

6. Future Directions

We can resume the Promising Directions As Follows:

- Machine Learning Integration: Use machine learning methods to automate the process of creating ontologies in SEE, minimizing the amount of manual labor required.
- Improved User Profiling: Create more comprehensive user profiling methods in SEE to better capture user preferences and deliver personalized information.
- Mobile Accessibility: Extend the methodologies to handle the unique issues of web data accessibility on mobile devices, taking into account various input modalities and screen sizes.
- Continued Standardization: Promote the continued standardization and upgrading of ARIA specifications in order to solve growing difficulties in web development and accessibility.
- Collaboration with Developers: Encourage web developers and accessibility specialists to work together to close the gap and ensure that both ARIA and SEE principles are effectively implemented.

7. Future Concerns of Web Data for Visually Impaired

The technological landscape is always changing, as are the needs of users, particularly those with visual impairments. As we work to create a more inclusive and accessible digital world, it is critical to anticipate future concerns about web data accessibility. By addressing these problems, we can ensure that technological improvements continue to meet the evolving needs of visually impaired people.

- **Emerging Technologies and Trends**

The field of web data accessibility is likely to see the incorporation of new technologies and trends. Machine learning and artificial intelligence could play a critical role in creating more sophisticated and context-aware assistive technology. Predictive algorithms may improve the user experience by predicting user demands and providing customized accessibility solutions.

Furthermore, advances in natural language processing may result in more sophisticated speech interfaces, making it easier for visually impaired people to engage with and understand complicated data sets. Exploring the use of haptic feedback or augmented reality for data interpretation could also lead to new paths for improved accessibility.

- **Collaboration and Standards**

Future paths in web data accessibility will benefit from closer collaboration among researchers, developers, and organizations. Establishing and refining accessibility standards should continue to be a top focus, ensuring that web content follows criteria that encourage inclusivity. Collaboration across industries can result in the creation of more complete solutions that address a broader range of user requirements.

- **User-Centered Design Iterations**

Continual iterations of user-centered design concepts will be required to create interfaces that really suit the demands of visually impaired users. Regular user feedback and usability testing should be included in the design process to identify and address any new difficulties or chances for improvement.

- **Personalization and Customization**

Recognising the different demands of the visually impaired community, future orientations should focus on personalized and customisable solutions. Giving consumers the flexibility to customize their digital experience based on their specific tastes and needs would improve the overall effectiveness of web data accessibility solutions.

- **Ethical Considerations**

As technology advances, ethical considerations become more significant. Future directions should include ethical frameworks that value user privacy, consent, and security. Ensuring that web data accessibility solutions are responsibly developed and deployed will help to create a more inclusive and trustworthy digital world.

To summarize, by actively addressing these future problems and embracing developing technologies, the field of web data accessibility for visually impaired users may adapt to the changing technology landscape and user requirements. We can work together to create a more inclusive digital future for all users by developing standards, iterating on user-centered design, personalizing, and considering ethics.

Bibliography

1. A. F. Siu, D. Fan, G. S. Kim, H. V. Rao, X. Vazquez, S. O'Modhrain, and S. Follmer, "Covid-19 highlights the issues facing blind and visually impaired people in accessing data on the web," in *Proceedings of the 18th International Web for All Conference*, pp. 1–15, 2021.

2. M. Costabel, "Being blind in a digital world — lacuna voices," Mar 2021. https://www.lacunavoices.com/explore-world-with-lacuna-voices/being-blind-in-digital-world-social-media-inernet-accessibility.

3. SAS Institute Inc 2013. SAS/ACCESS® 9.4. Cary, NC: SAS Institute Inc."Sas documentation." https://support.sas.com/en/documentation.html.

4. C. R. Beal and L. P. Rosenblum, "Use of an accessible ipad app and supplemental graphics to build mathematics skills: Feasibility study results," *Journal of Visual Impairment and Blindness*, vol. 109, no. 5, pp. 383–394, 2015.

5. K. Walker, "Modern day technology: Not accessible to all, but necessary to navigate this society," *Syracuse J. Sci. and Tech. L.*, vol. 35, p. 98, 2018.

6. R. Mancilla and B. A. Frey, *Guide to Digital Accessibility: Policies, Practices, and Professional Development*. Taylor and Francis, 2023.

7. A. Nazemi, "A method to provide accessibility for visual components to vision impaired," *International Journal of Recent Trends in Human Computer Interaction*, vol. 4, no. 1, pp. 54–69, 2013.

8. "Screen reader plus keyboard helps blind, low-vision users browse modern web- pages." https://www.rehacare.com/en/Archive/Archive_search/Screen_reader_plus_keyboard_helps_blind,_low-vision_users_browse_modern_webpages.

9. Accessibility | Bridgeway Education. (2018, August 30). Bridgeway Education https://www.bridgewayed.com/accessibility-services/

10. WebAIM: Designing for Screen Reader Compatibility. (2017, April 21) Copyright © 1999-2024 WebAIM (Web Accessibility in Mind). https://webaim.org/techniques/screenreader/

11. Joey G., (2016, January 7). Advantages and Disadvantages of Using a Screen Reader Instead of Braille.https://www.blindstreet.com/advantages-disadvantages-using-screen-reader-instead-braille/

12. Imre Verhoeven, STUDIO IMRE - TIME&EXPERIENCE, Rotterdam, South Holland, Netherlands, "Client work." https://studioimre.com/portfolio/Client%20work.html.

13. M. Rastovac, J. Dolic, J. Pibernik, and L. Mandić, "User-centered approach to product design for people with visual impairments," pp. 267–273, 11 2018.

14. Devin Coldewey, “TechCrunch is part of the Yahoo family of brands”, (2023, March 17). https://techcrunch.com/2023/03/17/the-monarch-could-be-the-next-big-thing-in-braille/

15. S. A. Doore, J. Dimmel, T. M. Kaplan, B. A. Guenther, and N. A. Giudice, “Multimodal- ity as universality: Designing inclusive accessibility to graphical information,” in *Frontiers in Education*, vol. 8, p. 1071759, Frontiers, 2023.

16. P. C. E. Team, “Digital accessibility: Understanding screen reader interaction,” Aug 2023. https://medium.com/prudential-design/digital-accessibility-understanding-screen-reader-

17. W. Yu, K. Kangas, and S. Brewster, “Web-based haptic applications for blind people to create virtual graphs,” in *11th Symposium on Haptic Interfaces for Virtual Environment and Teleoperator Systems, 2003. HAPTICS 2003. Proceedings.*, pp. 318–325, IEEE, 2003.

18. [29 U.S.C. 701 note] SHORT TITLE. This Act may be cited as the ‘‘Rehabilitation Act of 1973", “U.S. Access Board.” https://www.access-board.gov/about/law/ra.html.

19. The MirandaNet Fellowship, BrainPOP Educators Copyright © 1999-2024 BrainPOP, “Gaming research archives brainpop educators2015, Nov2015.

20. K. Rivenburgh, “WCAG 101: Understanding the web content accessibility guidelines,” Jun 2022. https://wcag.com/resource/what-is-wcag/.

21. S. Arruda, “Website accessibility: A guide for canadian car dealers,” Jun 2022. https://go.trader.ca/website-accessibility-a-guide-for-canadian-cardealers/.

22. B. Caldwell, M. Cooper, L. G. Reid, G. Vanderheiden, W. Chisholm, J. Slatin, and J. White, “Web content accessibility guidelines (wcag) 2.0,” *WWW Consortium (W3C)*, vol. 290, pp. 1– 34, 2008.

23. The Gale encyclopedia of public health, Illinois University Library, © 2020 University of Illinois Board of Trustees, “Blind/visual impairment: Home.” https://guides.library.illinois.edu/blind/visualimpairment.

24. T. Hermann and H. Ritter, “Listen to your data: Model-based sonification for data analysis,” *Advances in intelligent computing and multimedia systems*, vol. 8, pp. 189–194, 1999.

25. P. Morville and L. Rosenfeld, *Information architecture for the World Wide Web: Designing large-scale web sites*. " O’Reilly Media, Inc.", 2006.

26. L. M. Holloway, C. Goncu, A. Ilsar, M. Butler, and K. Marriott, “Infosonics: Accessible infographics for people who are blind using sonification and voice,” in *Proceedings of the 2022 CHI Conference on Human Factors in Computing Systems*, CHI ’22, (New York, NY, USA), Association for Computing Machinery, 2022. https://doi.org/10.1145/3491102.3517465.

27. L. M. Brown and S. A. Brewster, “Drawing by ear: Interpreting sonified line graphs,” International Conference on Auditory Display, 2003.

28. Tudor Paul Scripor, “Scripor alphabet, a self-orientation map using the tactile alphabet of colors in romania - scripor2022*, Jul*2022.

29. C. Fogle-Hatch, “Tactile access and the 3d-printing process,” Mar 2023. https://museumsenses.org/tactile-access-and-the-3d-printing-process/.

30. “Screen reader support for excel – Microsoft support.”https://support.microsoft.com/en-au/office/screen-reader-support-for-excel-0976b140-7033-4e2d-8887-187280701bf8.

31. A. Wyatt, “Complex compound formatting (microsoft word).”https://word.tips.net/T005396_Complex_Compound_Formatting.html.

32. David Rutter, “How do you translate sentences into math notation?.” https://www.quora.com/How-do-you-translate.

33. C. Keilers, G. W. Tigwell, and R. L. Peiris, “Data visualization accessibility for blind and low vision audiences,” in *International Conference on Human-Computer Interaction*, pp. 399–413, Springer, 2023.

34. M. C. N. Carvalho, F. S. Dias, A. G. S. Reis, and A. P. Freire, “Accessibility and usability problems encountered on websites and applications in mobile devices by blind and normal-vision users,” in *Proceedings of the 33rd Annual ACM symposium on applied computing*, pp. 2022– 2029, 2018.

35. C. Grodach, “Art spaces, public space, and the link to community development,” *Community Development Journal*, vol. 45, no. 4, pp. 474–493, 2010.

36. E. Lisney, J. Bowen, K. Hearn, and M. Zedda, “Museums and technology: Being inclusive helps accessibility for all,” *Curator: The Museum Journal*, vol. 56, pp. 353–361, 07 2013.

37. M. Bengisu, G. Izbirak, and A. Mackieh, “Work-related challenges for individuals who are visually impaired in turkey,” *Journal of visual impairment and blindness*, vol. 102, pp. 284–294, 05 2008.

38. A. M. Research, “Assistive technologies for visually impaired market 2019: Inspiring the technologists of the future - vfo, dol,” Oct 2019. https://www.openpr.com/news/1842613/assistive-technologies-for-visually-impaired-market-2019.

39. M. Hersh and M. Johnson, *Assistive Technology for Visually Impaired and Blind People*. 01 2008.

40. Jessica Lachance, Elections Canada, “Making data visualizations accessible to blind and visually impaired people2023, Mar2023. https://www.statcan.gc.ca/en/data-science/network/data-visualizations-accessible

41. A. Barros, “A practical guide to web accessibility: Part 1: Is my website accessible?,” Oct 2020. https://dev.to/aryclenio/a-practical-guide-to-web-accessibility-part-1-is-my-website-ac

42. Lucia Hasty, “Tactile graphics for students who are blind or visually impaired 8211; perkins school for the blind2022, Oct2022. *https://www.perkins.org/resource/tactile-graphics-students-who-are-blind-or-visually-impaired/*.

43. “Adline media - best 3d printing company in saudi arabia.” https://adlinemedia.sa/ service/3d-printing.

44. S. Decker, S. Melnik, F. Van Harmelen, D. Fensel, M. Klein, J. Broekstra, M. Erdmann, and I. Horrocks, “The semantic web: The roles of xml and rdf,” *IEEE Internet computing*, vol. 4, no. 5, pp. 63–73, 2000.

45. “Rdf semantics.” Copyright © 2004 W3C® https://www.w3.org/TR/rdf-mt/.

46. Copyright © 2024 World Wide Web Consortium, “Owl 2 web ontology language document overview (second edition).” https://www.w3.org/ TR/owl2-overview/.

47. Copyright © 2015 W3C® (MIT, ERCIM, Keio, Beihang) “Rdfa lite 1.1 - second edition2015, Mar2015. Patrick J. Hayes, Florida IHMC Peter F. Patel-Schneider, Nuance Communications.

48. B. Semaan, J. Tekli, Y. B. Issa, G. Tekli, and R. Chbeir, “Toward enhancing web accessibility for blind users through the semantic web,” pp. 247–256, 2013.

49. “Browsealoud is now the reachdeck toolbar.” https://www.texthelp.com/products/reachdeck/ browsealoud-is-now-the-reachdeck-toolbar/, journal=Texthelp.

50. “Webaim: Screen reader user survey 4 results.” https://webaim.org/projects/screenreadersurvey4/.

51. T. Bank, “Mobile phone access reaches three quarters of planet’s population,” *World Bank Group Press Release*, vol. 15, 2012.

52. Copyright © 2024 Apple Inc., “Accessibility - vision.” https://www.apple.com/accessibility/vision/.

53. C. Southern, J. Clawson, B. Frey, G. Abowd, and M. Romero, “An evaluation of brailletouch: mobile touchscreen text entry for the visually impaired,” in *Proceedings of the 14th international conference on Human-computer interaction with mobile devices and services*, pp. 317–326, 2012.

54. G. Bhirani, “What is the meaning of assistive technology (at)? - technology,” May 2021. https://www.mapsofindia.com/my-india/technology/what-is-the-meaning-of-assistive-technology-a

55. A. Cooper, R. Reimann, and D. Cronin, *About Face 3: The Essentials of Interaction Design*. 05 2007.

56. J. Lazar, A. Dudley-Sponaugle, and K.-D. Greenidge, “Improving web accessibility: a study of webmaster perceptions,” Mar 2004. https://doi.org/10.1016/j.chb.2003.10.018.

57. Story, Molly Follette; Mueller, James L.; Mace, Ronald L., "The universal design file: Designing for people of all ages and abilities. revised edition.." https://eric.ed.gov/?id=ED460554.

58. Preiser, Ostroff, Preiser, Wolfgang F. E, & Ostroff, Elaine. (2001). *Universal design handbook / Wolfgang F.E. Preiser, editor in chief ; Elaine Ostroff, senior editor ; foreword by Robert Ivy.* McGraw-Hill.

59. S. B. Jones, M. E. Lewin, *et al.*, "Reaching and educating medicare beneficiaries about choice," in *Improving the Medicare Market: Adding Choice and Protections*, National Academies Press (US), 1996.

60. J. McNeil, *Americans with disabilities, 1997*. No. 73, US Department of Commerce, Economics and Statistics Administration, Census2001.

61. M. L. Jones and J. A. Sanford, "People with mobility impairments in the united states today and in 2010," *Assistive Technology*, vol. 8, no. 1, pp. 43–53, 1996.

62. B. LaMendola, "Age-old question: How long can we live," *The Denver Post*, 1998.

63. J. P. Shapiro, *No pity: People with disabilities forging a new civil rights movement*. Crown, 1994.

64. P. Welch and C. Palames, "A brief Zettel, J. J., & Ballard, J. (1979). The education for all handicapped children act of 1975 PL 94-142: Its history, origins, and concepts. Journal of Education, 161(3), 5-22. of disability rights legislation in the united states,"

65. *Welch, P. (Ed.). (1995), Strategies for teaching universal design. Boston, MA: Adaptive Environments Center*, 1995.

66. David Sloan, Chieko Asakawa, Hironobu Takagi, Proceedings of the International Cross-Disciplinary Conference on Web Accessibility, W4A 2009, Madrid, Spain, April 20-21, 2009.

67. T. Berners-Lee, J. Hendler, and O. Lassila, "The semantic web," *Scientific american*, vol. 284, no. 5, pp. 34–43, 2001.

68. S. Horton and W. Quesenbery, *A web for everyone: Designing accessible user experiences*. Rosenfeld Media, 2014.

69. W3C "Content accessibility guidelines (wcag) 2.0." https://www.w3.org/TR/WCAG20/.

70. J. P. Bigham, C. Jayant, H. Ji, G. Little, A. Miller, R. C. Miller, R. Miller, A. Tatarowicz, B. White, S. White, et al., "Vizwiz: nearly real-time answers to visual questions," in Proceedings of the 23nd annual ACM symposium on User interface software and technology, pp. 333–342, 2010.

71. J. A. Jacko, I. U. Scott, F. Sainfort, K. P. Moloney, T. Kongnakorn, B. S. Zorich, and V. K. Emery, "Effects of multimodal feedback on the performance of older adults with normal and impaired vision," *Lecture Notes in Computer Science*, p. 3–22, 2003. http://dx.doi.org/10. 1007/3-540-36572-9_1.

72. S. Trewin, S. Basson, M. Muller, S. Branham, J. Treviranus, D. Gruen, D. Hebert, N. Lyckowski, and E. Manser, "Considerations for ai fairness for people with disabilities," *AI Matters*, vol. 5, p. 40–63, dec 2019. https://doi.org/10.1145/3362077.3362086.

73. C. Bernareggi, C. Comaschi, A. Marcante, P. Mussio, L. Parasiliti Provenza, and S. Vanzi, "A multimodal interactive system to create and explore graph structures," in *CHI'08 extended abstracts on human factors in computing systems*, pp. 2697–2702, 2008.

74. J. Wang, S. Wang, and Y. Zhang, "Artificial intelligence for visually impaired," *Displays*, 02 2023.

75. T. Hermann, A. Hunt, J. G. Neuhoff, *et al.*, *The sonification handbook*, vol. 1. Logos Verlag Berlin, 2011.

76. G. Kramer, B. Walker, T. Bonebright, P. Cook, J. H. Flowers, N. Miner, and J. Neuhoff, "Sonification report: Status of the field and research agenda," 2010.

77. "City research online - welcome to city research online." https://openaccess.city.ac.uk/.

78. M. Broussard, *Artificial unintelligence: How computers misunderstand the world*. mit Press, 2018.

79. WAI - ARIA "Accessible rich internet applications (wai-aria) 1.1.2017, *Dec*2017. https://www.w3.org/TR/wai-aria-1.1

80. WAI - ARIA, "Wai - aria overview." https://www.w3.org/WAI/standards-guidelines/ aria/.

81. "Accessible rich internet applications (wai-aria) 1.2.*2023, Jun2023.* "Aria in html2023*, Dec*2023. *https://www.w3.org/TR/wai-aria-1.2*

82. "Accessible rich internet applications (wai-aria) 1.1.*2017, Dec*2017. https://www.w3.org/TR/wai-aria-1.1

83. "Rdf vocabulary description language 1.0: Rdf schema." https://www.w3.org/2001/sw/ RDFCore/Schema/200212bwm/.

84. "Rdfa core 1.1 - third edition2015*, Mar*2015. https://www.w3.org/TR/rdfa-core

85. "Owl 2 web ontology language document overview (second edition)." https://www.w3.org/ TR/owl2-overview/.

86. G. Lorenzo, H. Hacid, H.-y. Paik, and B. Benatallah, "Data integration in mashups," *SIGMOD Record*, vol. 38, pp. 59–66, 06 2009.

87. F. Marquis, (2023, September 18). ARIA: Your Key to Unlocking Better Web Accessibility. Accessi Blog - ADA, WCAG, AODA, and Web Accessibility. https://www.accessi.org/blog/the-role-of-aria-in-web-accessibility/.

88. What is Accessibility? (2024, February 1). The Interaction Design Foundation. https://www.interaction-design.org/literature/topics/accessibility.

89. A. Haria, A. Subramanian, N. Asokkumar, S. Poddar, & J. Nayak. (2017), Hand Gesture Recognition for Human Computer Interaction. Procedia Computer Science. 115. 367-374. 10.1016/j.procs.2017.09.092.

90. Henry, S. L., & Hodges, L. F. (2009), Cognitive Disabilities and Web Usability. Proceedings of the International Cross-Disciplinary Conference on Web Accessibility (W4A).

91. Brajnik, G., & Gabrielli, S. (2008), Cognitive accessibility of websites for blind users: An empirical evaluation with blind users. Interacting with Computers, 20(4-5), 422-436.

92. Piumsomboon, T., Clark, A., Lee, G. A., & Ens, B. (2016). "Accessibility in augmented reality: An exploratory study." Proceedings of the 2016 CHI Conference on Human Factors in Computing Systems, 759-771

93. Goodman-Deane, J., Waller, S., & Boucher, A. (2012). "Inclusive interaction design: A literature review." Inclusive Interaction: Designing for Diverse User Needs, 9-40.

94. Diakopoulos, N. (2016). "Automating the verification of claims in journalism." Digital Journalism, 4(6), 799-819.

95. Y. Bengio, I. Goodfellow, and A. Courville, Deep learning, vol. 1. MIT press Cambridge, MA, USA, 2017.

96. K. O'Shea and R. Nash, "An introduction to convolutional neural networks," arXiv preprint arXiv:1511.08458, 2015.

97. upGrad. Neural Network: Architecture, Components & Top Algorithms. Upgrad. Retrieved September 21, 2022, from https://www.upgrad.com/blog/neural-network-architecture-components-algorithms/

98. S. Sharma, "Neural network: Architecture, components & top algorithms | upgrad blog." https://towardsdatascience.com/epoch-vs-iterations-vs-batch-size-4dfb9c7ce9c9/.

99. A. W. Services, "What is amazon machine learning?," Accessed 2023. https://docs.aws.amazon.com/machine-learning/latest/dg/what-is-amazon-machine-learning.html.

100. M. Mandal, "Introduction to convolutional neural networks (cnn)," May 2021.

101. P. T. (n.d.). *GitHub - Pankaj-Tarone/drishti: Drishti - Beyond The Sight*. GitHub. https://github.com/Pankaj-Tarone/drishti

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Declaration

I hereby declare that I completed this work independently and that I have used no aids other than those referenced.

The parts of the work, which include phrases or points taken from other sources, are clearly marked with the origin of the information. This also applies to diagrams, sketches, visual representations as well as for sources from the internet.

I also declare that I have not submitted this work in any other testing procedure as an examination paper, nor will in the future.

The submitted written work corresponds to the electronic version. I agree that an electronic copy may be made and stored to enable verification by anti-plagiarism software.

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