Assistive Technology

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Abstract Over the last three decades, the Web has become an increasingly important platform that affects every part of our lives: from requesting simple navigation instructions to active participating in political activities; from playing video games to remotely coordinate teams of professionals; from paying monthly bills to engaging is micro-funding activities. Missing on these opportunities is a strong vehicle of info-, economic-, and social-exclusion. For people with disabilities, accessing the Web is sometimes a challenging task. Assistive technologies are used to lower barriers and enable people to fully leverage all the opportunities available in (and through) the Web. This chapter introduces a brief overview of how both assistive technologies and the Web evolved over the years. It also considers some of the most commonly used assistive technologies as well as recent research efforts in the field of accessible computing. Finally, it provides a discussion of future directions for an inclusive Web.

Introduction

The Web is now ubiquitous in almost every facet of our lives. No longer is the Web merely our source of information, it has become the place we do business, communicate, socialise, shop, entertain ourselves and even receive health and social care. Many of us are never disconnected from the Web, thanks largely to the reduction in cost of portable and wireless mobile technologies, we live our lives both in the physical world around us and the virtual world that sites on top of it. The Modern Web has been integrated into the rich sensing capabilities of our ubiquitous computing devices, enabling novel interaction opportunities for content creators, and potential new challenges for people with disabilities.

While the first generation of the Web was predominantly static pages, that offered read-only experiences of published content from few savvy outlets and positioned the rest of us as information consumers. The Web we know today allows anyone to become a content creator, with purpose-built web tools and dedicated sites to support publishing of rich media and interactive content to the masses. They have quickly transformed the landscape of the Web and further solidified its position in society as the place where we communicate and share our ideas. Where previously the Web took a backseat to the accessing a physical instance or service, now we see many examples where the Web is the only way to access something including jobs, products, and financial support. To that end, it is now more vital than ever before that people have access to the Web, exclusion online will undoubtedly lead to exclusion in society. Therefore, we need to ensure that everyone has equal opportunity to access the Web regardless of any physical or cognitive abilities.

History of Assistive Technologies

Since the dawn of the human-computer interaction research field, several approaches to create accessible computing systems have been proposed. Unavoidably, many of them share the same overall goal: provide access to the widest range of users. This section describes some of the most relevant perspectives on accessible computing and how they evolved over time.

Assistive Technology is a term that includes all software and hardware solutions for people with disabilities (Cook and Hussey, 2001). Its main goal is to enable users to perform tasks they were once unable to accomplish, thus increasing their independence. These technologies are seen as being useful only to a minority by means of assistive components that bridge the gap between users and systems. Since these components are not part of the original solutions, they often require additional adaptation costs. Systems are seen as immutable entities and the burden of change lies with users. While this approach may be useful in some cases, such as for white canes, wheelchairs or hearing aids, it becomes obsolete when considering interactive computer systems. Approaches to Engineering Human Performance, focus on building models to provide effective system adaptations by matching the products' demands with users' capabilities (Kondraske, 1995; Persad et al., 2007). However, similarly to Assistive Technology, this approach assumes that the product is immutable.

From the mismatch between immutable systems and diversity of users' capabilities, two schools of thought emerged: designing for all and designing for the individual. Although they share the same goal of creating accessible computing systems, they have unique perspectives on how to tackle the overarching problem.

Stephanidis (1995) proposed the concept of User Interfaces for All (UI4All), promoting the use of unified interfaces to support user-independent interface development. In a unified user interface, only the core functionality is developed, while abstract user interface representations map to one concrete interface template, either at configuration- or run-time. Later, Universal Design (Vanderheiden, 1998), Design for All (Stephanidis and Salvendy, 1998), and Universal Usability proposed similar concepts and introduced the visionary goal of an information society for all. These approaches focus on applying a set of guidelines, methods, and tools to develop technological products and services that are accessible and usable by the widest range of users, therefore avoiding the need for adaptations. They follow an "one size fits all" approach to provide universal access.

The second school of taught was pioneered by Newel (1995) where he proposed the concept of Extra-Ordinary Human-Computer Interaction by depicting the parallel between "ordinary" people operating in "extraordinary" environments (e.g. adverse noise and lightning conditions) and "extra-ordinary" (disabled) users operating in ordinary environments. For the first time, the author relates individual human abilities to context. Later, Newel and Gregor (2000) proposed User-Sensitive Inclusive Design where they acknowledge that Design for All is a difficult, if not impossible, task:

> “Providing access to people with certain types of disability can make the product significantly more difficult to use by people without disabilities, and often impossible to use by people with a different type of disability".

The use of the term Inclusive rather than Universal reflects the view that Inclusivity is a more achievable, and in many situations, appropriate goal than Universal Design or Design for All.

More recently, Wobbrock et al. (2011) proposed Ability-Based Design, which focuses on users’ abilities throughout the design process in an effort to create systems that leverage the full range of individual potential. This concept provides a unified view of able-bodied and disabled users, as well as health- and context-related impairments (Sears et al., 2003). The authors focus on how systems can be made to fit the abilities of whoever uses them, either through automatic adaptation or customization. Unlike universal design approaches that design for what everyone can do, ability-based design focus on what the user can do.

Over the last two decades, the field of accessible computing has been evolving and consequently the term Assistive Technologies has also been shifting. It is nowadays an ‘umbrella’ term that includes a wide range of technologies from hardware and software to adaptive and customizable solutions. Throughout this chapter, we will use this wide definition when reporting on the several technologies that strive for inclusion of people with disabilities in the Web.

Modern Web Technology: HTML5

Tim Berners-Lee set out to create a network-accessible, organised store of information, built from documents that could be interconnected by their associations, providing effective means of navigation by its users. In the early years of the WorldWideWeb aka the Web, the documents and information were predominantly text documents described in HTML (HyperText Markup Language) which allowed for basic structure and formatting – such as headings and the essential hypertext links. The Web was intended for archival and publishing purposes, offering read-only interactions to its users.

Fast-forward a decade and the notion of a Web 2.0, a read-write web that would enabled bi-directional interaction. Where users were not simply content consumers of the Web, but its creators and curators. Everyone could participate and contribute to the vast, growing web of knowledge through personal blog and wikis; or curate and publish their own aggregations of web content using the popular RSS (Rich Site Summary) format. – making it possible for anyone to create associations between stored pieces of information and share them with the world. As the Web matured, so too did the infrastructure it was built upon – and so began the rise of the RIA (Rich Internet Application) leveraging the interactive affordances of the JavaScript, Flash and Flex languages.

The latest paradigm shift is known as the Semantic Web. Where previously information was structured and curated purely for humns, the Semantic Web aims to make a machine-readable web of data. Using the RDF (Resource Description Framework) specification, metadata can be associated with individual pieces of data allowing their discovery, description and reuse across applications and enterprises. In 2014 the W3C published the latest version of the HTML standard, HTML5, which boasted new features to better support mobile devices, natively handle multimedia content and new elements to enrich the semantic description of page content. DOM (Document Object Model) has also been included as part of the HTML5 specification, providing a tree structure representation of the page that can be programmatically read and manipulated. DOM integration is key to the success of many Assistive Technologies discussed within this chapter.

```html
<!DOCTYPE html>
<html>
    <head>
        <meta charset="UTF-8">
        <title>Document title</title>
    </head>
    <body>
        <header>
            <nav>
                <a href="/">Home</a></li>
                <a href="/about/">About</a></li>
                <a href="/contact/">Contact</a></li>
            </nav>
            <h1>Top-level heading</h1>
        </header>
        <main>
            <article>
                <header>
                    <h2>Sub-heading</h2>
                    <p>articles should be used to describe independent, self-contented content.</p>
                </header>
                <p>the body content of the article.</p>
                <figure>
                    <img src="daschund.jpg" alt="two daschunds sleeping">
                    <figcaption>Fig1. -  Mac and Crunchie, Newcastle, UK.</figcaption>
                </figure>
            </article>
        </main>
        <footer>
            <p>Posted by: Hugo Nicolau and Kyle Montague</p>
        </footer>
    </body>
</html>
```

Fig. 1 - A sample Webpage which is marked up with HTML5 tags.

Fig. 1 illustrates the aforementioned newly added HTML5 semantic elements. Not only do these tags describe and structure the content to be displayed, they carry inherent meaning that can be leveraged by machines, browsers and assistive technologies. The <nav> tag is used here to define a set of navigation links, while <main> identifies the primary content of the document. Documents can consist of one or more <article> containers, which are used to describe self-contained pieces of content. Articles can define their own <header> to introduce the content, and <footer> to name the author and copyright details for the individual article.

Fig. 2 - How the HTML5 in Fig 1 would be rendered by a browser

While the HTML5 page contains semantic elements, the visual representation of the content is no different from traditional HTML using <div> containers to structure the content. However, these simply changes to the ways were built the web will enable new innovations in intelligent agents and assistive technologies to the benefit of everyone on the web.

In addition to the new semantic tags, HTML5 includes features to natively handle multimedia and graphical content and better support mobile devices with API (application programme interface) integration to leverage their rich sensing and interaction capabilities. HTML5 allows developers to directly work with a user's geolocation, camera, microphone, local storage, Bluetooth and soon NFC (Near Field Communication) sensing to create cross-platform context- and location-aware experiences that rival native mobile apps (Anthes, 2012). As more developers embrace HTML5 to create rich experiences for mobile devices; we can expect to see positive side effects for web accessibility. These websites were found to be inherently more accessible largely thanks to their design being intended to adapt to device specific characteristics (Richards et al., 2012), which in turn is advantageous for assistive technologies that augment the presentation and interaction experiences.

Visual Abilities

A screen reader is a technology that assists people with little or no functional vision in interacting with computing devices. It resorts to text-to-speech software to translate visual information of computer interfaces. Over the years, several screen readers have been developed to support various operating systems such as Microsoft Windows (e.g. JAWS, NVDA), Linux (e.g. ORCA), OSX/iOS (e.g. VoiceOver), and Android (e.g. Talkback). Web-based screen readers (Bigham, 2008) have also been developed and require no additional software to be installed on the client machine (e.g. WebAnywhere, ChromeVox). These assistive technologies capture the displayed information on the screen and provide a set of navigational commands to aid users in interacting with applications. Commands are usually keyboard shortcuts or touchscreen gestures. For instance, when using the built-in screen reader of Android, i.e. Talkback, users move their fingers on the screen and the interface elements being touched are read aloud. A double tap is used to select the last element. Horizontal swipes can also be used to scroll through all elements on display.

Most screen readers have some type of specialized web mode that enables quick navigation through the DOM structure. One could argue that screen readers no longer read the screen as they use the underlying structure of the page rather than the visual layout. Screen readers convert a two-dimensional page to a one-dimensional text string (i.e. linearization). Thus, browsing the Web can become a difficult and frustrating process (Borodin et al., 2010). To deal with these issues, researchers have been investigating novel ways of adapting web pages and their content (i.e. transcoding) to the needs of blind people (Lai, 2011; Ackermann et al., 2012; Yesilada et al. 2013; Valencia et al. 2013; Fernandes et al. 2015). Common approaches include using heuristics, users' preferences, annotations, and semantic information. Moreover, as the Web evolves, increasingly types of content are being used and generated by its users: from scientific formulas (Sorge et al., 2014) and diagrams (Sorge et al., 2015) to videos (Encelle et al., 2013) and other dynamic content (Brown et al., 2009). Current research efforts aim at providing blind users with the means to access and manipulate such content.

Screen readers are generally able of providing both speech and Braille output. The latter needs an external device, such as a Braille pin-display, and can be used as a complement or replacement of speech output. Braille pin-displays generally include a Braille keyboard and interactive tactile cells that enable novel shortcuts, text-entry, or even drawing (Bornschein et al., 2018). Recently, several research efforts aimed at leveraging Braille as an input method for touchscreen devices

(Southern et al., 2012; Azenkot et al., 2012; Trindade et al., 2018) as well as an output strategy (Nicolau et al., 2013, set al., 2015).

While screen readers and Braille-related devices were mainly developed for blind users, people what experience low-vision generally use a multitude of assistive technologies to access screen content, such as screen magnifiers, increased text size, inverted colours, text-to-speech, modified contrast, and zooming tools. Knowing what tools are available and how to use them efficiently can be challenging (Szpiro et al., 2016).

Speech input and conversational agents are another form of assistive technology that are being increasingly integrated on mobile platforms. Google Assistant and Siri enable users to perform numerous actions such as search the Internet or create calendar events solely using speech input. Commercial dictation systems such as Dragon Naturally Speaking are also used for text input. Additionally, users can speak commands such as “move left” and “undo” to edit text. Speech input has also been used to aid users in web browsing actions. Ashok et al. (2015) proposed a speech-enabled screen reader that leverages a custom dialog model, designed exclusively for nonvisual web access (Ashok et al., 2014). Although speech is a natural and efficient interaction modality it is often highly dependent recognition accuracy. These solutions are sometimes used in combination with keyboards as correcting input errors is a cumbersome and time-consuming process (Azenkot and Lee, 2013).

In recent years, we witnessed a novel trend of using the Web as a platform to improve accessibility, namely through human-computation. Human workers, volunteers, and friends can help blind people in multiple tasks (e.g. labelling, object recognition, navigation) with higher accuracy than automatic solutions (Takagi et al., 2008; Gardiner et al. 2015; Rodrigues et al., 2017). The Social Accessibility project was one of the first to connect blind users to volunteers who can help them solve web accessibility problems (Takagi et al., 2008). VizWiz (Bigham et al., 2010) recruits web-based workers to answer visual (real-world) questions in nearly real-time. Blind people take a picture, speak a question to be answered from the photo, and then receive answers in about 30 seconds. Commercial systems, such as BeMyEyes, have leverage this approach and extended it to live video calls.

Physical Abilities

Being able to physically interact with the browser is essential to engage with online content. The Web we know today boasts interfaces that are rich in interactive media; framed by complex screen layouts requiring a significant degree of control to navigate and move through them. Where previously websites consisted of large volumes of text and hyperlinks, requiring the user to perform a single click to select, modern websites now take advantage of expressive gestural inputs and create custom interface elements to produce completely bespoke and immersive experiences for their visitors. If not done right these rich interactive spaces can become physically demanding and challenging to explore, particularly for individuals that require assistive technologies to engage with them. There are positive measures that developers can take to support users with physical access needs, such as providing keyboard shortcuts and alternative modes of interaction. However, for a large population these provisions are not enough, and more is needed. Over the years there have been many technologies created to improve the physical accessibility of the Web, both hardware and software solutions.

A common software augmentation used by individuals with reduced motor control is Switch Access Scanning (SAS), whereby a selection focus indicator moves through the website highlighting (visually or otherwise) each item on the screen for a period of time. When the desired target is highlighted the user performs the selection interaction i.e. presses the switch. This method can be very slow depending on the scanning pattern (e.g. linear scanning from top left to bottom right, grouped scanning by rows then columns within the selected row) and the dwell time for selection. SAS bares some resemblances to non-visual screen exploration via a Screen Reader. SAS can also support text-entry with the addition of an on-screen soft keyboard; this approach is also used by many AAC interfaces as the input and outputs of SAS can be individually tailored with custom hardware or mixed-modalities for outputs, making it a strong candidate for universal access.

Gaze tracking technologies such as Tobii Dynavox1 are used by individuals that find traditional mouse pointer control challenging or impossible. Commodity gaze trackers consist of IR cameras that are able to track the pupil movements and fixations of the eye and map these to the onscreen pointer. Targets are typically selected based on a dwell or fixation over the intended element. Speech input and conversational agents, as used to support visual abilities, are also popular methods of interaction for individuals with reduced motor-control where their speech is otherwise unimpacted.

For individuals whom experience intermittent reduced motor control (e.g. people with Parkinson's Disease) or those with a higher degree of motor control, SAS are an excessive adaptation; solutions such as screen magnification to increase target sizes or personalisation of keyboard and mouse configurations to reduce unintentional inputs are more appropriate.

Other approaches to support target acquisition include predictive models for mouse endpoints (Ruiz et al. 2009, Dixon et al. 2012, Pasqual & Wobbrock, 2014) and adaptive gesture models for touchscreen interactions (Montague et al. 2014, Mott et al. 2016). However, the lack of mainstream support for these technologies

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[1] https://www.tobiidynavox.com/

means they are not widely adopted. Solutions that are better integrated into the browser or operating system hold greater potential for individuals with reduced motor control. IBM Research have proposed several examples such as, Trewin's Dynamic Keyboard, a desktop assistive technology which would simultaneously monitor and adjust keyboard configurations to correct for common input errors (Trewin, 2004).

Physical adaptation of computers and input devices to improve their accessibility is a well-documented strategy for many individuals with motor impairments, as evidenced by the wealth of Youtubers sharing their creations (Anthony et al. 2013). Given that an individual's needs are often in their nature unique to that individual, the Do-it-Yourself approach to assistive technology has become popular in recent years thanks to the rise in maker culture and the advancements in consumer electronics and 3D printers (Hurst and Tobias, 2011).

Through platforms like Thingiverse2, designers and makers have started to create a plethora of open source 3D models for everyday assistive technologies. Anyone can download these designs and customise and remix them to meet their individual preferences and needs - using freely available open source software. These are truly exciting innovations for the assistive technology domain.

Hearing Abilities

The Web is becoming increasingly media rich; from text and audio to video and immersive content. People who experience hearing loss and deafness usually need visual access to aural information. Common accessibility services include captioning and subtitles. These can be either open or closed. While closed captions/subtitles can be turned off, open captions/subtitles are part of the video itself. The Web has enabled these services to be provided via remotely-located captioning services for live events, such as classroom lectures, work meetings, personal conversations, public events, and so forth. For instance, Skype, a commercial video conference software, already provides real-time automatic subtitling (translation) services.

Although captioning solutions can be used in many domains, they have been particularly successful in educational and classroom settings (e.g. Federico and Furini, 2012; Lasecki et al., 2014a; Kushalnagar et al. 2017). While Automatic Speech Recognition has been proposed as a cost-effective solution (Federico and Furini, 2012; Berke et al., 2018), alternative approaches have leveraged non-experts crowd workers to provide real-time and accurate captions (Lasecki et al.,

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[2] https://www.thingiverse.com/

2012). Indeed, human computation has been promised as a technology for affordable, accurate, and real-time captioning in real-world conditions (Lasecki et al., 2014a; Gaur et al., 2016). This is in contrast with professional captioning services that can cost dozens of dollars per hour.

Other common approach to access aural information is via sign language translation. For many individuals, captioning can be difficult to follow when the speed of verbatim captioning exceeds their reading abilities (Jensema et al., 1996). While many use a sign language over a written language to communicate, sign language translation is less common in web content. Kushalnagar et al. (2017) proposed a closed ASL interpreting, which similarly to closed captioning can be to toggle on/off. Additionally, the closed interpreter's size, position, and transparency can be customizable. Similar work was proposed by Hughes et al. (2015) for mobile captions.

Recent developments in web technologies have enabled the creation of cross-platform accessibility services. Web services such as X3D are being leveraged in the creation of virtual signing characters in translation systems (Boulares and Jemni, 2012). Research into virtual characters has reach a level of refinement that is now possible to build a model of human form that is articulate and responsive to perform sign languages (Kipp et al., 2011). Nevertheless, producing linguistically accurate, easily understandable, and user acceptable virtual signers is an open challenge (Kacorri et al., 2017). Similarly, automatically recognize and understand sign language is an open research problem that can benefit Deaf signers (Huenerfauth and Hanson, 2009).

Finally, the Web has also been used as an authoring and sharing platform of educational resources that were hard to create just a few years ago. For instance, the ASL-STEM Forum3 is a grassroots online community that brings together educators, interpreters, captioners, and students to build and disseminate American Sign Language technical vocabulary.

Cognitive and Learning Abilities

Our cognitive function and learning abilities impact a wide range of interaction capabilities; spanning from the ways in which we do things, to the feelings we experience. When designing for cognitive and learning abilities it is vital to recognise the complexity of human cognition and the breadth of the individual functions. Given the challenges of this domain and the additional considerations

[3] https://aslstem.cs.washington.edu/

need to work people within this context, it is no surprise that it has received less attention that other more easily understood areas of accessible computing.

In reality it is impossible to distil a single checklist to create websites that are fully accessible by individuals with low cognitive and learning abilities. However, technologies that seek to reduce the complexity to consume and engage with the content or provide intelligent support, make the Web more inclusive to these individuals.

Text simplification, is a technique used to reduce the complexity of text by simplifying the structure and grammar while maintaining the underlying meaning and information. Both automatic (Watanabe et al., 2009) and human-computation solutions to summarise or re-narrate text on the web (Dinesh et al., 2011) have demonstrated the relatively simple workflows needed as well as the wider benefit to other web users (e.g. visually impaired people). With the current push to create a semantic web of machine-readable data, works exploring machine learning and text translation models could yield exciting new opportunities for more accessible text content on the web.

Beyond the complexity of the text itself, web accessibility researchers have also demonstrated the importance of text layout and presentation to create readable web content (de Santana et al., 2012; de Santana et al., 2013; Rello et al., 2012) including the selection of appropriate colours, fonts, visual presentation and supporting media types.

One of the most powerful things the web has enabled is communication – specifically the ability to be directly connected to a friend, family member or carer anywhere in the world via text, audio or video at the push of a button. The web holds tremendous potential to support individuals with cognitive impairments (and their caregivers) to maintain meaningful relationships and live independently, whilst receiving the support they need from family and loved ones (Martins et al. 2014).

Ageing

Older adults starting to use the web face difficulties distinct from younger users. Problems include navigating web pages (back and history functions), longer times to complete tasks, select targets, and links, finding new information, and revisiting sites. They usually require more practice than younger people (Sayago and Blat, 2007; Tullis, 2007; Fairweather, 2008), and present lower levels of confidence when using technology (Marquié, 2002).

It is worth highlighting that it is not age per se that affects older users' web experience but a combination of factors (Crabb and Hanson, 2016), including the type of and level of impairment. Some may not need any assistive technologies, other may need multiple technologies to access the Web. As age-related declines are often in more than one ability (and with various levels of impairment), their combination can make accessibility more challenging than for people with a single disability (Gregor et al., 2002).

Current browsers (and Operating Systems) already include several accessibility features, such as font enlargement, colour modification, screen magnification, and text declutter. Further adaptations that extended the browsers' functionality through scripting are available via add-ons. Examples include screen readers, voice input, display customization, and navigational enhancements. Although many options are already available, they required awareness of their existence and relevance to individual needs. Moreover, they require users to be able activate and customize them, which may require excessive cognitive demands.

Even when accessibility features are available they are usually grouped under the banner of "disability", which might not match users' views of themselves. Indeed, older people do not identify themselves as having impairments; rather, just as novice users with low computer literacy skills. Automated or semi-automated adaptations have been proposed as a solution to all these problems (Sloan et al., 2010); however, accurately detecting users' accessibility needs and selecting appropriate adaptations is an open research challenge.

Other approaches to assistive technologies include simplified browsers targeted at older, novice users (Muta et al., 2005; Milne et al., 2005). However, these solutions tend not to be used by the larger population since 1) it may be difficult to get help from people that are unfamiliar with the simplified browser, 2) they hide functionality, and 3) they mark the user as "different". Specialized browsers with voice augmentation have also been investigated (Sato et al., 2011), showing that they can increase confidence levels of older adults when accessing the web.

An interesting alternative to browsers consists in bypassing all learning challenges by resorting to familiar devices to access web content. SOMFA (Social Media For All) is a platform that finds, retrieves, transforms, and displays social media content over TV Sets (Borrino et al. 2009). Other example includes the CaringFamily service4 that enables older adults to use email via fax.

Over the years, solutions to web access have been increasingly considering older adults as individuals rather than disabled versions of younger users. They view web pages differently (Tullis, 2007), have unique browsing behaviours (Fairweather, 2008), and make conscious decisions about what technologies (not) to use (Knowles and Hanson, 2018).

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[4] www.caringfamily.com

Discussion

Beyond having access to the information contained within, the web serves a greater purpose within today's society - it is a communication infrastructure like no other before. Governments are using the web to engage and interact with their citizens on local democracy; Educational institutions have prioritised eLearning environments to students; Health and social care is shifting to data-driven and technology enabled consultations and interactions with patients. It is vital that everyone has equal access to the web and the services that exists within it.

Assistive Technologies work to support individuals overcoming those barriers to access by augmenting the ways in which the content is presented, navigated and manipulated. However, assistive technologies are not always mainstream, or can be mass produced, often resulting in added complexities to maintain support and significant costs to the end-user.

HTML5 specifications and the push to support a diverse set of personalised mobile experiences are helping to create a more malleable and accessible web. As the underlying structure of the web improves, new integrations and interaction adaptations are made possible, helping to create a more inclusive web.

While there is no doubt that number of assistive technologies have been designed to support specific abilities, such as braille displays for vision or gaze tracking for motor-control – many accommodate a broad range of needs and abilities (e.g. screen magnification and closed captioning), with some obtaining mainstream status; designed for ease and convenience, not "disabilities" (e.g. speech control and conversational agents).

As new technologies emerge there will always be the need for niche and bespoke adaptations to support individuals with differing abilities. However, the current vision for the Web is leading towards rich semantic document descriptions, supporting ubiquitous interactions through with flexible modes presentation and engagement tailored to the specific context, device and user.

Future Directions

Developments in assistive technologies have opened up the Web to user groups that experience some form of impairment. It is now possible to access a wide range of online applications and services that promote greater independence and quality of life. Still, much work remains to be done to build an inclusive Web.

We are increasingly witnessing the appearance of intelligent and personalized assistive technologies that adapt to people's abilities. Such technologies are powered by advances in machine learning techniques and/or human computation approaches. Having systems that continuously assess, model, and adapt themselves to individuals and situations is the holy grail of accessible computing.

It is also noteworthy that personalization is not restricted to software. The recent emergence of Makers movement (e.g. project e-NABLE5) and the renewed culture of gadget-oriented products, opened new and exciting opportunities for hardware customization. No longer must assistive technologies be produced in small volumes at significant cost to the manufacturer and end user, nor need they just be for utilitarian purposes. It is possible to design for fun, play, and games. This year Microsoft announced the launch of the Xbox Adaptive Controller6, a gamepad designed to be augmented and customised via simple plug-and-play connections to meet the individual needs of the gamer; Nintendo also announced Labo7, a DIY kit for creating custom gamepads with cardboard - trend that will hopefully continue in the future.

Authors' Opinion of the Field

Until recently, most Assistive Technologies focused on providing access to products or services via software or hardware solutions. However, in recent years, we have witnessed technologies that go beyond just "bridging the gap" between users and systems but use the Web as a platform for real-world inclusion. Examples include commercial tools such as Google Maps or BeMyEyes[8], or research projects such as VizWiz (Bigham et al., 2010), Legion Scribe (Lasecki et al., 2014a) or Tohme (Hara et al., 2014). These solutions open new opportunities for people with disabilities allowing them to perform tasks that were once arduous or impossible to accomplish in the real-world.

Despite all its potential, technology can equally impose new barriers to widen the "digital divide". Examples include people that make conscious decisions about not using certain technologies, which can result in different forms of social exclusion (Knowles and Hanson, 2018). It is therefore increasingly important to understand the broader impact of web technologies beyond traditional usability measures and focus on its impact on personal and social levels.

These are exciting times to create novel inclusive technologies that can have a broad impact on people's lives: from software solutions to Internet-enabled devices that sense and act on the built-environment.

[5] http://enablingthefuture.org/

[6] https://www.xbox.com/en-US/xbox-one/accessibility

[7] https://labo.nintendo.com/

[8] https://www.bemyeyes.com/

It is therefore crucial that accessibility studies aim to understand the broader impact of web technologies, beyond traditional performance measures and focus on its social impact.

Conclusions

Gone are the days when websites were designed to target to young, able-bodied, technology savvy users that would access the content from their keyboard and mouse desktop environments. Technology in one form or another has permeated into every facet of human lives spanning the broad range of demographics and severing a broader range of functions. Portable networked-devices have allowed us to form a symbiotic relationship with the Web, simultaneously drawing from and contributing to the vast knowledge base of interconnected documents and datasets. To deny access to such a resource seems criminal, yet for many individuals the much of the web remains inaccessible and unexplored.

Beyond having access to the information contained within, the web serves a greater purpose within today's society - it is a communication infrastructure like no other before. Governments are using the web to engage and interact with their citizens on local democracy; Educational institutions have prioritised eLearning environments to students; Health and social care is shifting to data-driven and technology enabled consultations and interactions with patients. It is vital that everyone has equal access to the web and the services that exists within it.

As the underlying technologies and conceptual vision of the web evolve to towards a semantic web of machine-readable data designed to be discovered, manipulated and presented in new forms, assistive technologies are well positioned to benefit from those efforts regardless of the developer's web accessibility knowledge.

New trends in human-computation and machine learning technologies, are bringing about a new era of assistive technologies designed to leverage the web to support interactions in the real-world. In particular, these innovations hold promise for individuals with reduced cognitive and learning abilities leading independent lives.

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