CodeTalk: Improving Programming Environment Accessibility for Visually Impaired Developers

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ABSTRACT
In recent times, programming environments like Visual Studio are widely used to enhance programmer productivity. However, inadequate accessibility prevents Visually Impaired (VI) developers from taking full advantage of these environments. In this paper, we focus on the accessibility challenges faced by the VI developers in using Graphical User Interface (GUI) based programming environments. Based on a survey of VI developers and based on two of the authors' personal experiences, we categorize the accessibility difficulties into *Discoverability, Glanceability, Navigability,* and *Alertability*. We propose solutions to some of these challenges and implement these in CodeTalk, a plugin for Visual Studio. We show how CodeTalk improves developer experience and share promising early feedback from VI developers who used our plugin.

Author Keywords
Accessibility; Programming Environments; Visually Impaired; Audio Debugging

ACM Classification Keywords
H.5.2. Information interfaces and presentation: User Interfaces

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INTRODUCTION
Software development is one of the fastest growing fields [10]. However, people with visual impairments are not very well represented in the field of computer science and software development: we are unaware of any formal study that confirms this. However, we consider the surprise with which the fact of blind programmers is received (see for example the comments in [15]) as an empirical confirmation. The percentage of developers who have self-reported as being blind in the 2017 Stack Overflow survey is about 1% which is much more than the percentage of people with visual impairments in the general population [11]. We believe that the 1% reflects that blind developers are happy with the Stack Overflow question and answer website because it is accessible and consequently use it in higher numbers. According to the US National Bureau of Labor statistics [21] only about 2% of workers in the computing and mathematical professions have a disability compared to the percentage of people with disabilities in the general population of the US which is about 19% according to the US Census Bureau. There are several reasons for this under-representation, and in this paper, we address one of them, namely the poor accessibility of developer tools.

People with visual impairments, use Assistive Technology (AT) like screen readers, screen magnifiers, and braille displays to access computers. They have also been using the same to write computer programs. In recent times, GUI based Integrated Development Environments (IDEs) have become more widely used [11]. These modern IDEs aid program comprehension and development by providing features like syntax highlighting, variable watch windows and ability to execute code both forward and backward [13] enabling developers to be more productive and efficient. Though screen readers provide basic accessibility to IDEs[1],

[1] From here on, we use IDEs interchangeably with GUI based IDEs

many features that IDEs indispensable to sighted developers remain inaccessible to developers using screen readers.

In this paper, we make the following contributions towards making programming environments more accessible to VI developers.

- We present a classification of accessibility issues in four headings: *discoverability*, *glanceability*, *navigability*, and *alertability* and provide illustrative examples of each kind. This classification was arrived at by combining the subjective experience of two of the authors with the results of a user survey on IDE accessibility.
- We propose solutions to address a subset of the identified issues and implement these solutions as CodeTalk, a plugin for Visual Studio. Unlike related work on accessibility of IDEs which address specific activities, we address accessibility issues across the entire spectrum of activities around software development from comprehending code, editing, debugging, and working with teams on large codebases.
- We present feedback that validates our approach by an exploratory user study with six VI developers using CodeTalk.

The paper is organized as follows: Section 2 describes the motivation for this work and summarizes related work. Section 3 presents a broad classification of accessibility issues in IDEs. In Section 4, we introduce our approaches to solve these issues and discuss details about CodeTalk, our Visual Studio plugin. In Section 5, we discuss an exploratory user study performed to get some initial user feedback on our approaches. Section 6 and Section 7 present the key conclusions and highlight several directions for future research.

MOTIVATION AND RELATED WORK

The major motivating factors for this research are the personal experiences of two of the authors A and B. Author A is a novice programmer who primarily used a command line interface and a text editor to program. A's attempt to move to an IDE like Visual Studio was unsuccessful since the accessibility issues were found to be too daunting without continuous help from a sighted person. Author B has been programming using a screen reader and B's experiences with IDEs involved significant effort in tackling inaccessibility. The author was able to cope by using text-based tools for academic work and part-time projects. However, moving to a large organization as part of a product team required that B use an IDE used by the other team members to work efficiently. At this point, the author realized why sighted developers were able to work at a much faster pace. They were able to read code much faster than the screen reader user, quickly comprehend the structure of huge code bases, be informed about errors without explicit actions and move to any part of the code by pointing and clicking. Motivated by these experiences, we surveyed earlier research efforts that address accessibility issues in programming environments.

IDE accessibility for developers with visual impairments is still a new research area. There is very little exploration that has been done to improve the development and programming experience for VI developers. That said, there has been interest in both academia and industry to improve the accessibility of developer tools. IDEs like Eclipse [6], Apple's XCode [7] and Microsoft's Visual Studio [4] have made continuous improvements in accessibility support for screen reader users. However, this accessibility support is quite limited to having all buttons and UI elements spoken in some cases. There have also been attempts by researchers to improve the accessibility of developer tools. Emacspeak [14] is an early effort to improve developer tools accessibility. More recently, Baker et al., [2] have addressed the difficulties faced by blind programmers while reading code. They describe StructJumper, an Eclipse plugin that displays an accessible tree-view of code structure with respect to the current line. This effort attempts to help VI developers get complete context with respect to a specific line of code. The plugin focuses on reading code effectively. Smith et al. [22] explain the problem of navigating hierarchical tree views in detail, and, propose requirements to make tree views more usable. [22] complements our work on glanceability and navigability in CodeTalk. The key difference is that CodeTalk lays down a framework to address a broad spectrum of challenges faced by VI developers using IDEs while [22] does an in-depth investigation on nonvisual navigation of hierarchical data.

Both speech and non-speech audio have been explored to enable VI developers to program. Sodbeans [19] and WAD [18] discuss approaches to use audio for debugging code. The Sodbeans plugin uses speech-based cues to enable VI developers to debug. WAD emphasizes on the developers' ability to comprehend the execution flow of the code.

[16] explores the use of auditory cues (Spearcons) in reading source code. The researchers synthesized source code with different audio cues like speech, tones, and white noise, using NVDA's speech output and Audacity. They used combinations of these audio cues to represent the code file. The participants were asked to comprehend code using these audio files. This effort demonstrated that relying solely on screen-reading is not sufficient for VI developers to comprehend code.

[8] uses 3D printed models for VIPs to explore program output. Students wrote programs to generate tactile versions of the data to explore program output. Efforts like [9] and [12] focus on teaching programming to blind students. As seen above, all the related research has focused on enabling VIPs to do specific tasks while programming. There is no work that addresses accessibility issues that arise across the complete program development cycle.

We do not address the larger challenge of building tools and languages that facilitate the learning of computer

programming. However, we point to some interesting efforts in this direction: Quorum [20] started out as a language that is easily accessible to screen readers but has since evolved to a much more general effort on evidence-based language design. The APL [17] is another effort to introduce programming to students with visual impairments. In this paper we focus on enhancing accessibility of IDEs to VIPs who have learnt the basics of programming and are currently users of IDEs.

To go beyond the specific experiences of the two authors mentioned and to understand the spectrum of accessibility issues that arise during the complete programming cycle, we conducted a user survey which we discuss in the next section.

Preliminary Survey

We conducted a preliminary survey with an objective to collect opinions from VI developers on IDE accessibility, with a specific focus on Microsoft Visual Studio. The survey was hosted online, and we made sure all parts of the survey were accessible to screen reader users. On completion of the survey, participants interested in giving more information could opt-in to participate in additional interviews by conveying their interest over email. Four out of the 20 participants of the survey participated in further detailed interviews. Details of the survey, including the questions, participants' demographic information and programming experience levels, etc., can be found in [1]. The learnings from the survey have been summarized in the next subsection.

Learnings from the Survey

The major observation we made when we collated the survey results and the interview responses, was that accessibility issues were present across the entire spectrum of software development. A sample of the responses to "list top 5 accessibility challenges" illustrates this very well:

- "watch windows are hard to use -specially the quick watch"
- "Solution Explorer hangs on very large solutions when attempting to navigate within",
- "Sometimes controls don't have labels and report their class name"
- "access to breakpoint status while debugging"
- "There is no alternate way to get to things if you don't know one of the thousands of shortcut commands"
- "difficulty in moving from error screen to the editor where program is present (Control + tab) doesn't work"
- "Access to variable type and other info (usually accessed by hovering the mouse over the variable name)"

These responses were from VI developers with experience ranging from a year to more than 25 years. The issues people face range from simple ones like "Difficult to determine when code is folded up (hidden) and must be expanded" to that of an advanced user's "That comparison tool is 100% inaccessible with screen readers so I have to configure my own code review tool in visual studio"

We then stepped back a bit to find if there is some structure to the numerous accessibility issues which will help us devise a solution process to handle them effectively. The result of this effort is the classification of accessibility challenges that we describe in the next section.

CLASSIFICATION OF ACCESSIBILITY CHALLENGES IN IDES

Based on the data from the accessibility survey, experience of the visually impaired authors, as well as related work on IDE accessibility, we classify accessibility challenges into four broad categories and give some example scenarios for each. We use examples from Visual Studio.

1. Discoverability: This is the ability with which a user can find features of the system to increase proficiency over time. Sighted users have many visual clues that indicate new features that could be useful for a given context, but VI developers need to depend on others to tell them about such features. Discoverability is an issue for sighted users as well but is exacerbated for VI developers. For instance, the author B was not aware of the variable watch window[2] and used console messages to find the variable values until pointed out by a sighted team member. The following are some examples of discoverability issues:
   - *Existing features:* Many features of the IDEs are overtly visible in the UI but are hidden inside multiple levels of navigational hierarchy for screen reader users.
   - *New and modified features:* With every new version of the IDE, new features get added and existing features are modified. Many of these changes are visually represented, and there is no structured approach for VI developers to be informed of the same. This becomes more evident when IDEs do a complete UI over haul, changing the UI hierarchy and arrangement.
2. Glanceability: Visual Studio and most IDEs by definition, use the large real estate provided by high resolution monitors to present many aspects of the program development process in one screen. Their success in improving developer productivity depends primarily on the ability of the developer to glance at various aspects of the development process presented to them at any given time. For sighted developers, glanceability is innate to the medium of information

[2] Watch window is used to evaluate variables and expressions during debugging.

access, vision. The IDEs leverage the high bandwidth nature of visual input and provide features that enable sighted developers to make sense of information by quickly glancing at the screen and the IDE's windows. Visual input, being a more active way of acquiring information gives an opportunity to unobtrusively provide information to the IDE's users without interrupting their current task. Unfortunately, these features are not available to the VI developers, and they often must consume information linearly. Following are some example situations:

- *Quick overview of the code structure:* Unlike sighted users, who can get the overview of the code structure by quickly scrolling up and down a page, the VI developer are forced to go through the code line by line.
- *Getting the context of the given line:* There are situations when the VI developer lands in an unknown line of code due to breakpoints or exceptions, or simply because the developer was distracted. On the other hand, based on the line number and the vertical slider bar's position, a sighted user has a notion of the size of the program file and the relative location of the cursor with respect to the beginning and the end of the file.
- *Indentation level:* Indentation levels in whitespace dependent programming languages like Python, are easy to perceive for sighted users unlike VI developers, who are forced to count the number of whitespaces for every line.
- At any given point, sighted developers can look at multiple pieces of information (the console log window, stack traces, the actual code and a lot more information as per the developer's preference). VI developers using screen readers have to get this information by explicitly changing focus on to each window in sequence.

3. Navigability: An added advantage for sighted developers is the ability to quickly navigate through code using scroll, point and click. Screen reader users are limited to the search functionality and few other navigation features provided by the IDEs. This also extends to navigating between multiple panes within the IDE. Following are some example scenarios:
   - *Skipping over large comments:* Sighted developers can skip over large code comments like documentation and licenses quickly as compared to screen reader users. It is cumbersome for VI developers to navigate to the end of these comments.
   - *Navigating through large blocks of code:* Sighted developers can scroll, point and click to navigate through blocks of code like if-else block, try-catch block. However, navigating through code within a block is not so intuitive and easy for VI developers using screen readers.
   - *Navigating across various windows:* Sighted developers can easily obtain information from multiple windows like the watch window, call stack window, and the debug window instantaneously without having to switch between them. On the other hand, VI developers must go through numerous keystrokes to switch between and access the information presented in these windows.

```
static void Main(string[] args)
{
    var dictionary = new Dictionary<string, int>(5);
    dictiona.Add("cat", 1);
    dictionary.Add(mouse, 5)
}
```

Figure 1. Red squiggle shown for error in Visual Studio

4. Alertability: IDEs convey a significant amount of real time information through a completely visual interface [2]. Such information alerts the developer to issues that need immediate attention or actions that are in progress. The following examples enumerate few scenarios where VI developers do not get access to the real time information provided by the IDE:
   - *Debugging Information:* Information related to debugging like values of variables and breakpoint information are not available to a VI developer unless explicit actions are performed.
   - *Error Information:* Syntax error information in IDEs is given by visual cues like red squiggles [Figure 1], which are not available to VI developers pro-actively.

These accessibility challenges result in a huge barrier for VI developers in exploiting the power of IDEs. Although one can bundle all these limitations and attribute them to the fact that sighted developers can either point-click or scroll-click while VI developers cannot, the above grouping helps us devise expedient alternates using a structured approach. We also note that these groupings helped organize our understanding of accessibility challenges and are not meant to be water tight compartments. In the next section we describe CodeTalk, our vehicle for addressing the above challenges.

CODETALK

CodeTalk is implemented as a Visual Studio plugin. CodeTalk works with Visual Studio versions 2015/2017 and supports C# and Python programming languages at the time of writing this paper. However, implementing support for newer languages is straightforward. We have chosen to implement CodeTalk as a Visual Studio plugin mainly due to the following reasons:

1. Visual Studio provides APIs that allows us to tap into all the IDE's features.
2. Visual Studio's increasing support for a variety of programming languages.
3. Free availability of Visual Studio community edition.

4. Visual Studio is the most popular IDE among developers [11].

In CodeTalk, we address the accessibility challenges categorized in the previous section by focusing on the root cause of the issues: Screen reader based access to information is user driven, unlike the use of a GUI by a sighted user. The user must actively seek out information from various components of the IDE. And since the information access with a screen reader is dependent on cursor focus, the user must explicitly set focus on the appropriate pane. In some situations, the VI developer might not be aware of the presence of a pane containing the information they are looking for. Our approach is to minimize the effort of the VI developer actively seeking information by proactive extraction and presentation of information or by introducing an audio channel distinct from the screen reader. CodeTalk extracts the information relevant to the context and makes it accessible to the developer with reduced effort. To this effect, we introduce new customizable keyboard shortcuts as shown in Table 1. We present below a few of the features of CodeTalk in detail.

Code Summary and Functions List

One of the first things a developer would want to do after opening a new code file is to understand its structure. Which file is this? What are the classes in this file? What are the functions in each class? VI developers get this information using standard navigation techniques like searching by name when known or by reading code one line at a time. In CodeTalk, we introduce a code summary feature. Using this, developers get an accessible tree view [Figure 2] containing the details about the namespaces, classes, and functions in the file. The developer[3] can explore the tree view and get an overall understanding of the code structure. Additionally, they can also navigate to the desired code component by pressing the enter key. The code summary feature helps VI developers get a "glance" of the different code constructs in the file.

We realized that one of the major constructs all developers frequently interact with are functions in a code file. To enable quick glanceability and navigability across functions in a file, we introduce a functions list view [Figure 3] that displays an accessible list view of all the functions in the current code file. Both the code summary and the functions list feature enable code glanceability and quick navigation of code.

Get Context of Current Line

Another important observation we made was that focus can move across lines or even code files while debugging or jumping to function definitions or usages. In these scenarios, a VI developer might be interested to know the context of the current line of code, at which the cursor is placed. Keeping this in mind, we introduce a feature that displays an accessible list view of the context hierarchy containing the enclosing block, function, class, and namespace that the current line of code belongs to.

Real-time Error Information

Most IDEs represent syntax errors in code via syntax coloring. In Visual Studio, this is done via red squiggles [Figure 1]. We bring this visual information to VI developers via pro-active error tones informing the developer about syntax errors. Developers can then press a keyboard shortcut to get an accessible list of errors.

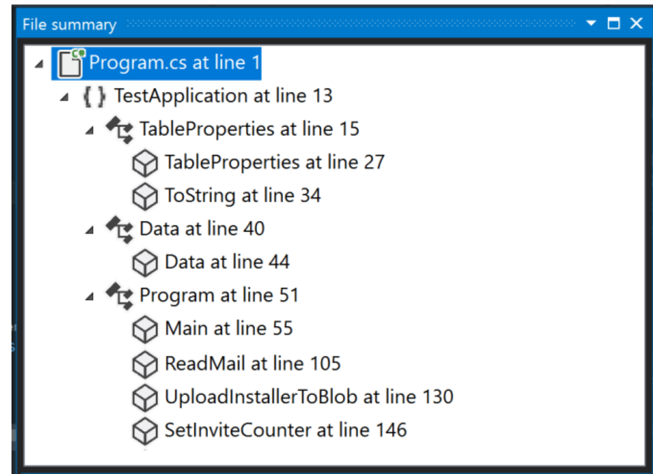

Figure 2. Code Summary containing tree view of code constructs

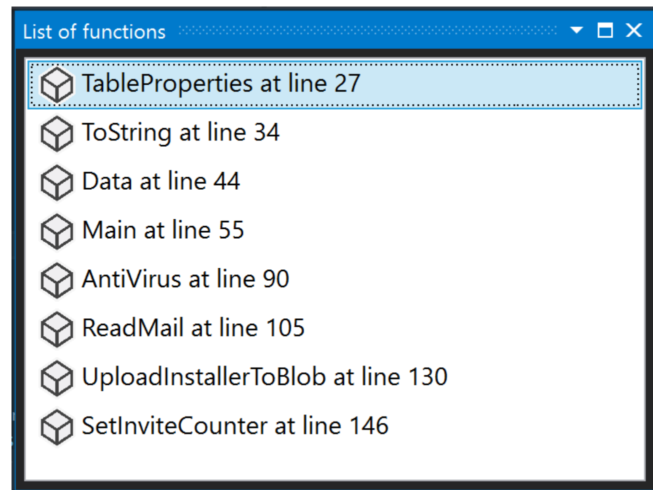

Figure 3. List of functions in the current code file.

Audio Debugging with TalkPoints

Debuggers are highly effective tools that assist developers in identifying bugs in their code. However, using debugger tools is not a very accessible experience and VI developers prefer printing console messages for debugging instead of

[3] From here on, by mentioning developer we mean VI developer, unless explicitly stated otherwise.

using a proper debugging tool [9]. While "printf debugging" can get the job done for small projects, the process gets very cumbersome for larger projects. It also creates code clutter that can lead to potential security vulnerabilities if not cleaned up later. There have been tools like WAD [18] and Sodbeans [19] that explore audio for debugging source code. WAD, for instance, focuses on conveying the execution flow to the user. Though this is a very important piece of information, developers often need to know this piece of information with respect to very small parts of the code. We propose a novel approach to audio debugging which (I) gives developers the option to choose between speech and non-speech based debugging and (II) gives developers information about specific variables or evaluates an expression in the execution context. (III) gives an option to break or continue execution after the audio cue. We have conceptualized and implemented three types of TalkPoints: *Message Talkpoints*, *Tone Talkpoints* and *Expression Talkpoints*.

Feature	Keyboard Command
Code summary	Control + ~, Control + m
Functions list	Control + ~, Control + f
Get context	Control + ~, Control + g
Move to context	Control + ~, Control + j
Error information	Control + ~, Control + e
TalkPoints	Control + ~, Control + b

Table 1. CodeTalk keyboard shortcuts.

Steps to add a TalkPoint are as follows:

1. Invoke add TalkPoint dialog, from the desired cursor position by pressing a key combination. [Table 1]

2. Select the TalkPoint type.

3. Choose whether to pause or continue execution using the continue checkbox.

4. Activate the TalkPoint using the add button.

Message TalkPoints

Message TalkPoints are similar to adding trace statements. However, one small yet significant differentiating factor is that "Message TalkPoints" speak out the message set by the developer when they are hit without the developer having to explicitly switch focus and search in the trace window.

Tone TalkPoints

Our rationale behind proposing and implementing Tone TalkPoints was that developers often only need to know the execution path of the program. For instance, the developer might want to know whether the execution entered an if, else or a catch block. The developer can accomplish this by setting a tone TalkPoint (at say, the entry of the block) and selecting a tone to be played when the TalkPoint is hit.

Expression TalkPoints

In many situations, developers are interested to know the value of a variable with respect to the execution context. With Expression TalkPoints, we give developers the ability to have values of specific variables spoken to them when these TalkPoints are hit. Assume the user wants to insert an expression in the following code:

```
int[] array = { 1, 2, 3, 4, 5, 6, 7, 8 };
int count = 0;
for (int i = 0; i < array.Length(); i++)
{
        count = count + array[i];
        //do something here.
}
```

Let us say the developer wants to track the value of the variable "count". They can simply insert an Expression TalkPoint at line 5 as *"value of count is:"* + count. When the program is executed, the expression is run in the current breakpoint context, and the result is spoken to the developer. In the above case it will be: "value of count is 0", "value of count is 1", etc.

CodeTalk Design

CodeTalk's design is both modular and extensible. Even though the current implementation is for Visual Studio IDE, CodeTalk can be easily implemented for other IDEs and even other languages. CodeTalk mainly consists of the following components.

- Keyboard manager
- Command objects
- Plugin outputs
- Language service and language specific implementations

Keyboard manager: This is responsible for capturing keyboard shortcuts, validating them and relaying it to the appropriate command objects

Command objects: These objects encapsulate the end to end functionality for a specific user command and send the output to the appropriate output block.

Plugin output: This module handles outputs from the command object. The output can be of various forms:

- *Dialogs:* IDE dialogs containing output entities in a list or tree view. For instance, function list command gives a dialog containing list view of all the functions.
- *Editor modifications:* Moving the cursor to a specific line in the code file. For instance, move to context command moves the cursor to the beginning of the context block.
- *Audio:* Synthesized audio sent to the default system audio output using Speech Synthesis APIs.

Language service and language specific implementations: At the heart of CodeTalk design is the Language service component. This component defines interfaces for

understanding code which are invoked by command objects to provide CodeTalk functionality. Language-specific implementations implement these interfaces to add support for the corresponding language.

The C# implementation in CodeTalk leverages the Roslyn APIs [5] to implement the Language service interfaces. For Python implementation, CodeTalk uses IronPython APIs [3]. For functionalities that require keyboard shortcuts, we chose user-customizable key commands like those provided by Visual Studio.

Bootstrapping CodeTalk

One of our authors, B, has been implementing and using CodeTalk since its initial implementations. This exercise helped us evolve CodeTalk's feature set based on the author's needs. Also, the initial user survey was a reference to us to ensure that the features we implement would help a larger audience.

Author B was already familiar with using an IDE and was encouraged by the improvement in productivity due to CodeTalk right from the first set of features implemented: "functions list view" and "code summary". The author used the plugin for their development and perceived significant benefit while trying to make sense of code written by other members of the project.

The next set of features implemented were "get context", "move to context", and "error information". The "get context" and "move to context" features helped B quickly understand and navigate classes. Though a reasonably experienced programmer, B was relatively new to the C# programming language. Prior to implementing the error list and real-time error information features, the author had to fix syntax issues only by building the project. This build and fix approach was a major productivity hiccup for B, as the project took minutes to build and syntax errors were not available until the build completed. B observed a significant improvement in productivity due to the error list and real-time error information features as it didn't require explicitly building the project; Another major observation was that compiler error messages were easier to understand if attended to immediately as opposed to building after accumulating a few of them. Prior to implementing TalkPoints, the author B was very reluctant to use a debugger, often resorting to printf debugging. There were several occasions when B received code review comments asking for the removal of printf/log statements.

To verify if our approaches helped more developers, we performed an exploratory user study with 6 VI developers proficient with coding. We excluded novice programmers and those learning to program from this study since our current focus is not on discoverability, but to improve the productivity of already competent VI developers.

EXPLORATORY USER STUDY

We conducted an exploratory study with an objective of getting feedback from active Visual Studio programmers to validate the direction we were taking and to get a preliminary idea of the utility of CodeTalk's features. As mentioned in the conclusion, a rigorous study is needed to identify the strengths and drawbacks of our approach. The study had four major components: Participant solicitation, user study without and with CodeTalk, and post user study online survey.

Participant solicitation

We circulated a short online survey to get basic information of interested participants. We wanted participants who code in C# or Python using Microsoft's Visual Studio 2015 and above.

We selected 6 participants who were reasonably experienced with writing code in C# and using Visual Studio. All the participants opted in to the study by sharing their email address and signed a consent form regarding our terms of study.

Setup for the Study

Since the study was conducted remotely, we setup a remote Virtual Machine (VM) on Microsoft's Azure platform, to observe the participants. The VM had the NVDA screen reader installed. To ensure that developers were comfortable with our screen reader setup, we allowed them to connect to the VM a few hours in advance of the scheduled study time. Developers were also allowed to install any screen reader plugins and configure the screen reader to match their preferences. Most participants using NVDA preferred to connect using the NVDA Remote add-on. However, we requested participants to switch to Microsoft's remote desktop to perform tasks 3, 4, and 5 of phase 2 as the NVDA Remote add-on does not pass through system audio. Switching to a remote desktop did not result in any change in screen reader behavior.

JAWS users, however could not use the remote VM as JAWS does not allow activations on Virtual Machines even with the remote desktop add-on. We allowed participants using JAWS to connect to a physical machine via JAWS Tandem or remote desktop.

Participants connected with us over a Skype audio call and shared their screen with us. This helped us observe user behavior. We recorded participant's microphone audio, our microphone audio and their screen's video for our observation and further analysis.

Phase 1: Performing programming tasks without CodeTalk

In this phase, participants were asked to perform five programming tasks using Visual Studio without the CodeTalk plugin installed. The aim of this phase was to establish a baseline for how each participant used the IDE. This phase also helped us better introduce our problem and plugin to the participant. Before performing the tasks, we asked participants about the general issues they faced as a VI developer when using IDEs.

The programming tasks we chose did not require developers to switch between multiple files. The participants performed the following tasks.

1. Describe the hierarchical structure of a code file (namespace, classes, and methods) in a project.
2. Go to a specified line in a code file using Visual Studio's go to line function and describe the enclosing context (enclosing method, class, and namespace information) with respect to the current line.
3. Open a code file containing syntax errors and fix them.
4. Identify if running a project results in the control entering a catch block. Participants were not allowed to modify the code unless they were unable to perform the task without modifying the code.
5. Find the value of a variable after the ith of a loop without modifying the code. The loop read data from a file and participants were not allowed to look at the file. Participants were allowed to modify the code if they were unable to perform the task.

Phase 2: Performing programming tasks with CodeTalk Installed

On completion of phase 1, we introduced participants to CodeTalk, our accessibility plugin for Visual Studio. Participants were allowed to explore the plugin after the walk-through and we ensured they could quickly lookup CodeTalk keyboard shortcuts if required. Participants were given the same tasks as in the previous phase albeit with different code files. We did not make the use of CodeTalk mandatory for this phase. The participants could choose to use CodeTalk if they wanted to. We wanted to observe the developers' behavior given the tool. After the tasks, we asked the developers four questions.

1. How was your experience in doing the with and without CodeTalk?
2. Was there any more information you wish you had while doing these tasks?
3. How often do you encounter these tasks in your day to day programming?
4. Did CodeTalk help in solving the given tasks?

After these questions, the participants were asked to give general feedback on the plugin and the user study. Towards the end of the call, we asked participants to fill a short online survey[4].

Participant demographics

We had a total of six participants in the exploratory study. All participants have been coding for more than a year. Two of them have been programming for about 3-5 years, one for about 5-10 years and two for more than 10 years [Table 2]. All participants were male and completely blind. Five of the participants reported they have been using a computer for more than10 years. Participants were from the United States, United Kingdom, Spain, India and Romania. All participants were familiar with C#.

Observations from the User Studies

[Table 3] shows the average rating for our plugin's features. Participants were asked to rate the plugin's features on a scale of 10 (1 being not useful and 10 being extremely useful). CodeTalk's utility was rated on average 8.83 by the participants. We also describe our observations on participant's IDE usage while performing tasks in both phases.

Participant	Programming Experience
P1	1 – 2 years
P2	3 – 5 years
P3	3 – 5 years
P4	Above 10 years
P5	5 – 10 years
P6	Above 10 years

Table 2. Participant Demographics

Feature	Average Rating (on a scale of 10)
Navigability features (*Code summary, Get context, Function list*, etc.)	8.83
Real time error information (*Pro-active error beeps* and *Error list*)	8.33
Audio debugging (*Tonal*, *Textual* and *Expression TalkPoints*)	8.5

Table 3. Participant ratings of CodeTalk features.

Task 1: Reporting code summary

In the first phase, three out of the six participants navigated through code one line at a time to give us the summary. P3, P4 and P6 used an IDE feature to navigate through different classes and functions of the file. P4 and P6 had developed their own navigation techniques using some of Visual Studio's features. P4 first navigated to the beginning of the namespace and then to the end. He followed a similar approach for all the blocks. However, this technique involved navigating through code one line at a time. P6, on the other hand, navigated by first folding the code and then navigating through the folded code. In phase 2 however, all participants preferred to use CodeTalk's code summary feature to report the summary. All participants except P2 mentioned that this is especially useful to quickly understand large code files and code written by other developers. P2

[4] We asked for their email ID in the survey for compensating them later and mentioned this in the survey.

however accepted that they work on their own code most of the time and so would not need to get the summary of code. However, they accepted that "code summary" feature could come in handy in situations where they must read code written by others. P3, who used the IDE's feature to get the structure of code still preferred to use CodeTalk. *"Using this code summary does not require me to move focus away from my IDE; I know that pressing enter or escape on the dialog box will get me back to the file I was working on."* was P3's feedback on completing task 1. P4 commented: *"Having a keyboard shortcut to get the tree structure, is very nice. It is just there. I do not have to use my methods anymore. This is better as it is right there and gives me just the summary."*

Task 2: Report context of a specific line

In this task, participants were asked to go to a line using Visual Studio's "go to" line feature. Participants were then asked to report the context (enclosing function, classes and namespaces) that the line belongs to. Three out of the six participants preferred to navigate through the code one line at a time. The code had a nested class. Which was not discovered by three out of the six participants as they had moved all the way to the top of the file to report the namespace after finding one of the class's declaration statements. In phase 2 however, all participants chose to use CodeTalk's get context feature to complete the task. They mentioned that this feature would come in handy specially when they want to debug or when they are taken to a line of code by the IDE due to a breakpoint or exception.

Task 3: Fix syntax errors and build

In this task, developers were given code that had syntax errors. Participants had to fix the errors and then build the project. The initial action of all the participants excluding P2 was to try and read the code. Then, all participants except P2 built the project to check for syntax errors. P2 used other IDE features to fix the errors. In phase 2, all participants except P2 preferred to use CodeTalk's Error information features as it did not require building the project explicitly.

Task 4: Report whether the catch block is executed

In this task, developers were given a code file with a try and a catch block and were asked whether the catch block be executed if the code is run. The initial constraint for this task was that the participants could not modify code. The rationale behind putting this constraint is to examine if the participants were familiar with breakpoints. Three out of the six participants could not perform this task without modifying code; they mentioned that they did not find debuggers accessible, did not use breakpoints and had to resort to "printf debugging". Participants could report the answer to us once we allowed them to modify code. In Phase 2, Participants were able to perform this task very easily and they chose to make use of CodeTalk's Tone TalkPoints to identify whether the catch block was executed. *"I like the idea of breakpoints not breaking, and simply continuing after playing the audio."*, exclaimed participant P2.

Task 5: Find value of a variable at runtime

In this task, participants were given code that iterates over a list of numbers in a for loop and adds them to a variable "sum". They were asked to report the value of the variable "sum" after the ith iteration. The numbers were populated from file which the participants didn't have access to. To perform this task, participants had two major constraints:

- Participants cannot modify code.
- Participants cannot read the file from which the values are loaded.

All participants except P1 could complete this task in both phases. In the first phase, four out of the six participants could not do it without modifying code. When allowed to modify code, three out of these four participants reported the value by adding console statements. One participant, P1, could not finish the task in both phases. In the second phase four of the five participants who finished the task used Tone TalkPoints (4.4.2) whereas one participant, P5, used a combination of a Tone TalkPoint and Visual Studio's locals window to check for variable values.

Participants responded positively when they were asked whether they encountered these tasks as a part of their day to day programming. P2 however, did mention that they did not encounter task one (reporting the summary of the code) frequently as they mostly work on their own code, but also said *"this is definitely useful for situations where I have to look at other people's code"*. *"Yes, I find myself doing these things quite frequently, during my assignments"* was P3's feedback.

Participants were asked about their experience about the plugin and the user study in general. *"I never knew how much information I was not getting because I was using a screen reader. I had no clue sighted users had this much information available."* said P1. P1 also mentioned that they had difficulty in sorting through code in the post user study survey. "I have difficulty to sort through code. Perhaps this is due to my vision impairment and not really an accessibility issue" said P1. It was a surprising observation for us that VI developers blamed themselves for these hindrances and did not view them as deficiencies in the accessibility of the tool.

DISCUSSION

We believe that stepping back and looking at the nature of accessibility challenges in the use of IDEs has been very fruitful. The organization of these into four categories, discoverability, glanceability, navigability and alertability, has given us a structure to classify specific problems and to solve them using the accumulated tools built to solve earlier problems. In implementing CodeTalk we identified two key ideas to help address these problems: the first is to extract relevant information from the IDE that is spread around visually and present them directly in summary form to the VI developer. The second is to present additional information through a secondary audio channel distinct from the screen reader. A combination of these two ideas have been used to

address a subset of the identified challenges in the current version of CodeTalk. However, this systematic framework has opened numerous possibilities for future research that we outline below.

The notion of TalkPoints has tremendous promise, not just for VI developers, but even for sighted users. The introduction of the auxiliary audio channel opens an additional bandwidth for the users. In particular, Expression TalkPoints have the potential to monitor and announce subtle inter relations between functions and can be a powerful debugging tool.

Promising initial user feedback shows that our approach and CodeTalk have a positive impact on VI developers' productivity. It has also given us considerable feedback and additional insights which we intend to build on. However, we need to explore evaluation metrics for the effectiveness of these solutions and conduct more systematic user studies. How can we say CodeTalk has enhanced productivity? Do we measure the time taken to accomplish individual tasks with and without CodeTalk? Or since VI developers using IDEs depend extensively on keyboard shortcuts, should we measure this improvement by logging keystrokes? Do we just compare VI developers with and without CodeTalk or compare VI developers with sighted users since the goal of such accessibility work is to bridge the gap between the two? These are some of the many interesting questions that we have begun to grapple with in evaluating CodeTalk.

We also want focus on a broad class of issues that fall under discoverability. Currently, getting started with Visual Studio and similar IDEs requires significant hand-holding from sighted peers. Discoverability issues are a major reason for author A not switching to an IDE. Even experienced VI developers who have used an IDE for a long time are frequently surprised by new features they stumble upon accidentally. Given the complexity of modern IDEs, it is not practical to go through each one of the menu items or to exhaustively read the user manual to discover all the features.

In addition, this is rarely useful for a novice programmer and unproductive for experienced users. We need to devise new techniques that can gently induce the user to discover features when it is most useful. Such discoverability, even for sighted users, is still a challenge and it is a wide-open area of research.

Control of navigation granularity is a very widely used feature by screen reader users. Web navigation is generally through different HTML elements like headings, form controls, links etc. We would like to explore similar granular navigation techniques specific to code especially for easy navigation through classes, functions and inner code blocks.

Our choice of implementing CodeTalk as a plugin allows us to build these solutions in a manner that can easily be ported across IDEs. We have open sourced our implementation to facilitate further rapid development and research[5]. Additionally, from user feedback, there is a need for CodeTalk to support more popular scripting languages like JavaScript.

CONCLUSION

We grouped the numerous accessibility challenges faced by VI developers in using GUI based programming environments into four categories, namely, discoverability, glanceability, navigability and alertability. We presented CodeTalk, a plugin for Visual Studio that enables VI developers to overcome some of these challenges. Participants in the exploratory user study have given very positive feedback on the utility and potential of CodeTalk to improve accessibility. We also presented several possible research directions that emerge from this work.

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REFERENCES

1. Vidhya Y. 2017. Preliminary Survey Responses. Supplementary material - SurveyResponses.pdf. (2017).
2. Catherine M Baker, Lauren R Milne, and Richard E Ladner. 2015. Structjumper: A tool to help blind programmers navigate and understand the structure of code. In *Proceedings of the 33rd Annual ACM Conference on Human Factors in Computing Systems*. ACM, 3043–3052.
3. IronPython Community. 2017. IronPython. Retrieved September 19, 2017 from http://ironpython.net/.
4. Microsoft Corporation. 2017. Microsoft Visual Studio. Retrieved September 19, 2017 from http://www.visualstudio.com.
5. .Net Foundation. 2017a. Roslyn. Retrieved September 19, 2017 from https://github.com/dotnet/roslyn.
6. The Eclipse Foundation. 2017b. Eclipse. Retrieved September 19, 2017 https://eclipse.org/.
7. Apple INC. 2017. XCode. Retrieved September 19, 2017 from https://developer.apple.com/xcode/.
8. Shaun K Kane and Jeffrey P Bigham. 2014. Tracking@ stemxcomet: teaching programming to blind students via 3D printing, crisis management, and twitter. In *Proceedings of the 45th ACM technical symposium on Computer science education*. ACM, 247–252.
9. Sean Mealin and Emerson Murphy-Hill. 2012. An exploratory study of blind software developers. In

[5] http://github.com/Microsoft/CodeTalk

Visual Languages and Human-Centric Computing (VL/HCC), 2012 IEEE Symposium on. IEEE, 71–74.

10. U.S. Bureau of Labor Statistics. 2016. Software Developers: Occupational Outlook Handbook: U.S. bureau of Labor Statistics. Retrieved September 19, 2017 from https://www.bls.gov/ooh/computer-and-information-technology/software-developers.htm.
11. Stack Overflow. 2017. Stack Overflow Developer Survey 2017. Retrieved September 19, 2017 from https://insights.stackoverflow.com/survey/2017.
12. Charles B Owen, Sarah Coburn, and J Castor. 2014. Teaching Modern Object-Oriented Programming to the Blind: An Instructor and Student Experience. *In ASEE Annual Conference.*
13. Guillaume Pothier, Éric Tanter, and José Piquer. 2007. Scalable omniscient debugging. *ACM SIGPLAN Notices* 42, 10 (2007), 535–552.
14. TV Raman. 1996. Emacspeak-A Speech Interface. In *Proceedings of the SIGCHI conference on Human factors in computing systems.* ACM, 66–71.
15. Reddit. 2017. Can I still be a Computer Scientist if I'm Blind?: cscareerquestions. Retrieved September 19, 2017 https://www.reddit.com/r/cscareerquestions/comments/3e844q/can_i_still_be_a_computer_scientist_if_im_blind/.
16. Dominic Roberts and Karlton Weaver. 2011. Audio Aids in Source Code. Retrieved September 19, 2017 from http://archive2.cra.org/Activities/craw_archive/dmp/awards/2011/Roberts/FinalPaper.pdf.
17. Jaime Sanchez and Fernando Aguayo. 2004. Listen what I do: blind learners programming through audio. *Memorias TISE* (2004), 120–124.
18. Andreas Stefik, Roger Alexander, Robert Patterson, and Jonathan Brown. 2007. WAD: A feasibility study using the wicked audio debugger. In *Program Comprehension, 2007. ICPC'07. 15th IEEE International Conference on.* IEEE, 69–80.
19. Andreas Stefik, Andrew Haywood, Shahzada Mansoor, Brock Dunda, and Daniel Garcia. 2009. Sodbeans. In *Program Comprehension, 2009. ICPC'09. IEEE 17th International Conference on.* IEEE, 293–294.
20. Andreas M Stefik, Christopher Hundhausen, and Derrick Smith. 2011. On the design of an educational infrastructure for the blind and visually impaired in computer science. In *Proceedings of the 42nd ACM technical symposium on Computer science education*. ACM, 571–576.
21. U.S. Bureau of Labor Statistics. 2016. Economic News Release: Table 3. Employed persons by disability status, occupation, and sex, 2016 annual averages. Retrieved September 19, 2017 from https://www.bls.gov/news.release/disabl.t03.htm.
22. Ann C Smith, Justin S Cook, Joan M Francioni, Asif Hossain, Mohd Anwar, and M Fayezur Rahman. 2004. Nonvisual tool for navigating hierarchical structures. In *ACM SIGACCESS Accessibility and Computing.* ACM, 133–139.